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RESONANT FREQUENCIES AND MODE SHAPES FOR SINGLE AND DOUBLE CYLINDRICAL SHELLS

C. B. Burroughs, S. I. Hayek,
D. A. Bostian and J. E. Hallander

Technical Memorandum
File No. TM 83-169
23 September 1983
Contract N00024-79-C-6043

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Resonant frequencies and mode shapes for single and double cylindrical shells are identified from measurements made with the shells in air and in water. The single shell assembly consists of five ribbed sections bolted together and closed at each end with watertight endcaps. Outer shells are wrapped around the inner shell assembly to produce the double shell assembly. The space between the inner and outer shells is free flooded. Resonant

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frequencies are reported for frequencies up to 1000 Hz. For frequencies above 1000 Hz the resonant modal density is too high to allow separation of all of the resonant frequencies. Because of the limited number of accelerometers inside the shell assembly, only the first eight resonant bending modes are identified. It is shown that submerging the shell assembly in water reduces the resonant frequencies of the lowest bending modes to nearly one half of the frequencies for the shell assembly in air.

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From: C. B. Burroughs [2], S. I. Hayek [2], D. A. Bostian and J. E. Hallander

Subject: Resonant Frequencies and Mode Shapes for Single and Double Cylindrical Shells

Abstract: Resonant frequencies and mode shapes for single and double cylindrical shells are identified from measurements made with the shells in air and in water. The single shell assembly consists of five ribbed sections bolted together and closed at each end with watertight endcaps. Outer shells are wrapped around the inner shell assembly to produce the double shell assembly. The space between the inner and outer shells is free flooded. Resonant frequencies are reported for frequencies up to 1000 Hz. For frequencies above 1000 Hz the resonant modal density is too high to allow separation of all of the resonant frequencies. Because of the limited number of accelerometers inside the shell assembly, only the first eight resonant bending modes are identified. It is shown that submerging the shell assembly in water reduces the resonant frequencies of the lowest bending modes to nearly one half of the frequencies for the shell assembly in air.

1. Introduction

ARL/PSU has been tasked by ONR, Code 474, to conduct farfield acoustic radiation and acoustic scattering measurements on a ring-stiffened circular cylindrical shell assembly submerged in water with and without outer shells wrapped around the cylindrical shell. With the outer shells, the shell assembly is double walled and is referred to as the double shell assembly. Without the outer shells, the shell assembly is referred to as the single shell assembly. Before conducting measurements at the NUSC Transducer Calibration Platform (TCP) on Lake Seneca, measurements of the resonant structural responses of the single and double shell assemblies were conducted at ARL/PSU. The objectives of these measurements are:

(1) To determine the frequencies at which there are peaks in the shell response and therefore the frequencies where peaks in the acoustic radiation may occur, and

(2) To compare measured with predicted results as an intermediate step in the validation of numerical models used by Weidlinger Associates to predict acoustic radiation and by the Lockheed Palo Alto Research Laboratory to predict acoustic scattering.

At low frequencies, where the modal density of the shell assembly is small enough that the modes are separable, the peaks in the acoustic radiation occur at frequencies where the shell response peaks. In order to separate peaks in the acoustic radiation caused by structural resonances from peaks caused by other mechanisms, such as peaks in the radiation efficiency due to wavenumber scattering from the internal ribs, the resonant frequencies of the single and double shell assemblies were measured at ARL/PSU.

In addition to the need to identify structural resonances to assist in the analysis of the measured acoustic radiation data, the measured data on the resonant frequencies will be used to help validate numerical models. Weidlinger Associates has been tasked by ONR to exercise numerical models to predict the acoustic radiation from the ARL/PSU shell assemblies. As a first step in validating the numerical models, predictions of the resonant frequencies and mode shapes of the single and double shells, in air and in water, will be compared to the resonant frequencies and mode shapes measured by ARL/PSU and reported here. Lockheed Palo Alto Research Laboratory has been tasked by ONR to predict the acoustic scattering from the ARL/PSU shell assemblies. As a part of validating the numerical models that they will use to make these predictions, comparisons of predicted resonant frequencies and mode shapes will be made to measured resonant frequencies and mode shapes presented in this memo.

2. Description of Measurements

2.1 Shell Assemblies

The single shell assembly consists of five nominally-identical shell sections bolted together along the joint bands at the end of each shell section. The ends of the single shell assembly are closed by endcaps bolted to the shells along joint bands.

Sketches are given in Figures 1, 2 and 3 of side, top and end views, respectively, of one of the shell sections. The shells are made of aluminum and each of the shell sections weighs 166 lbs. A sketch of the joint band, showing the coupling of the shell sections, is given in Figure 4. As shown in Figures 1 and 2, each shell section contains two hand holes. Opposite to the hand holes are two longitudinal rails running

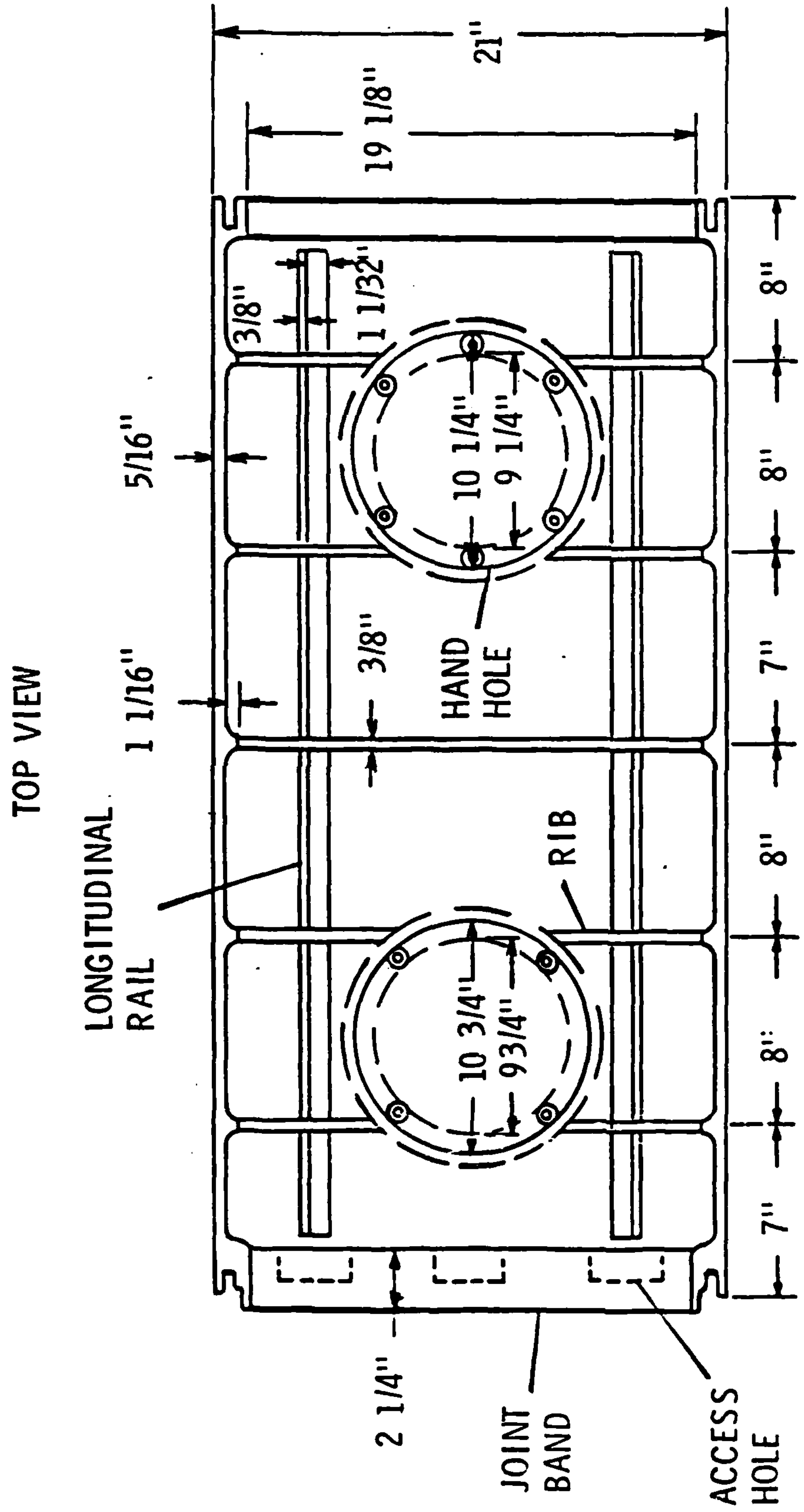


Figure 1. Top View of Shell Section

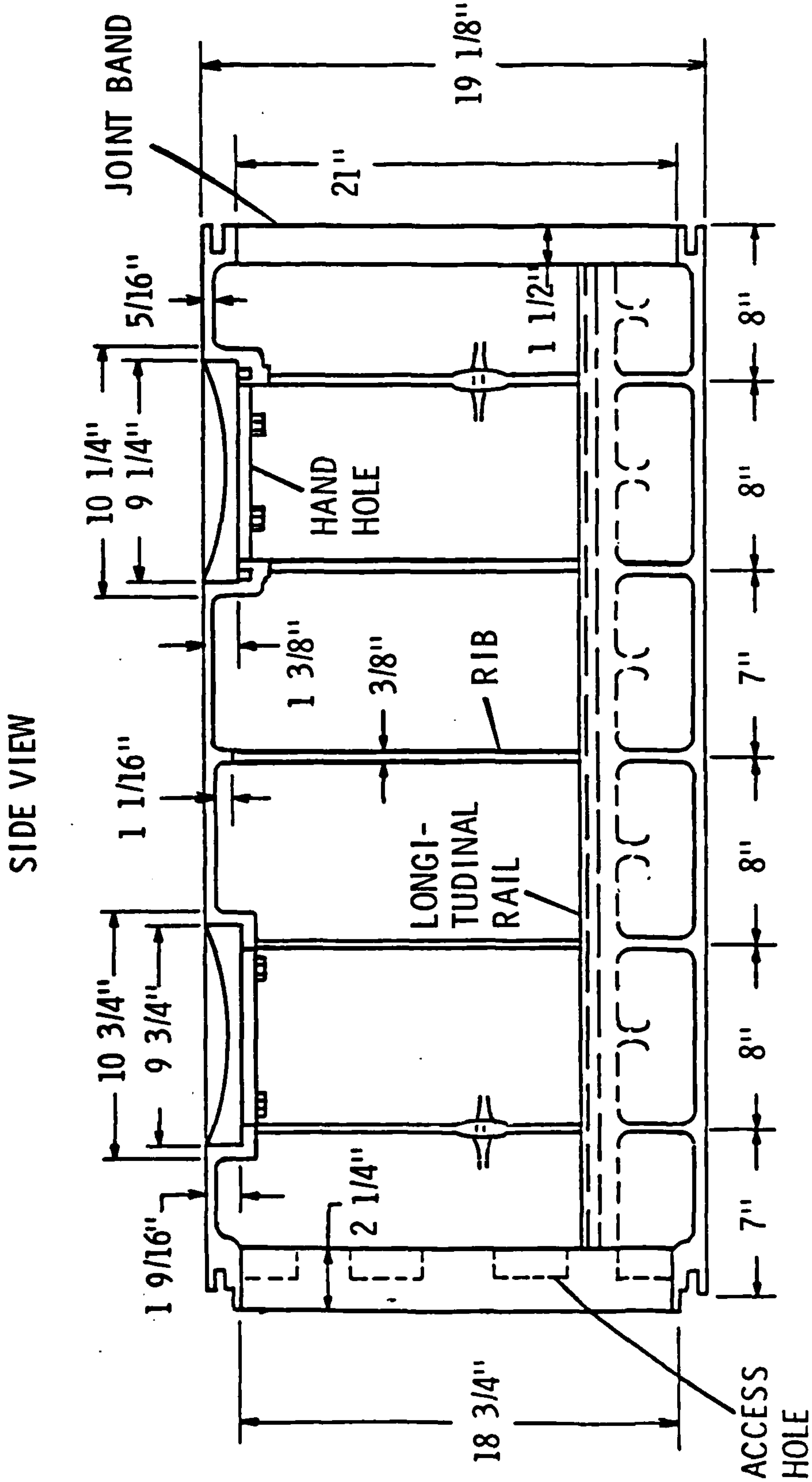


Figure 2. Side View of Shell Section

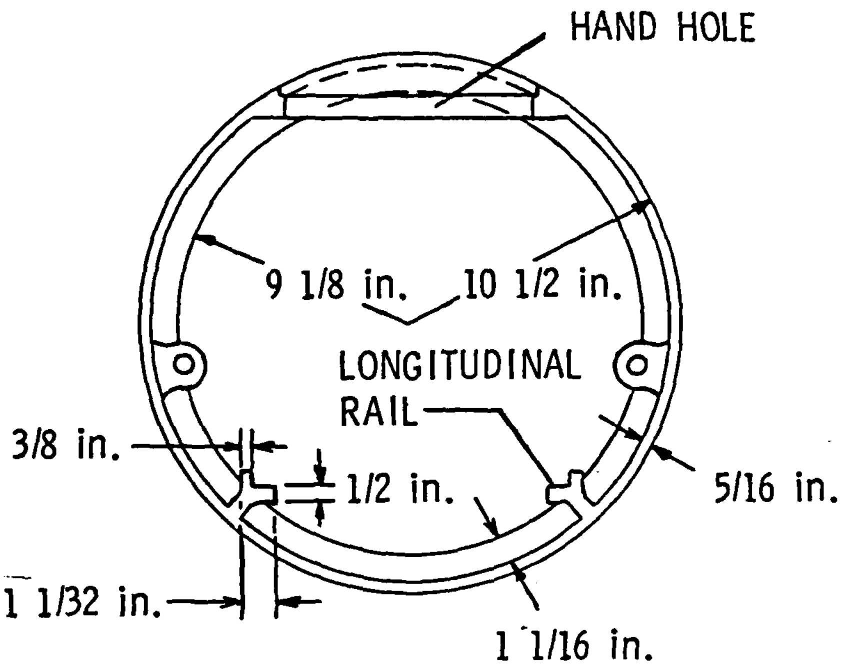


Figure 3. End View of Shell Section

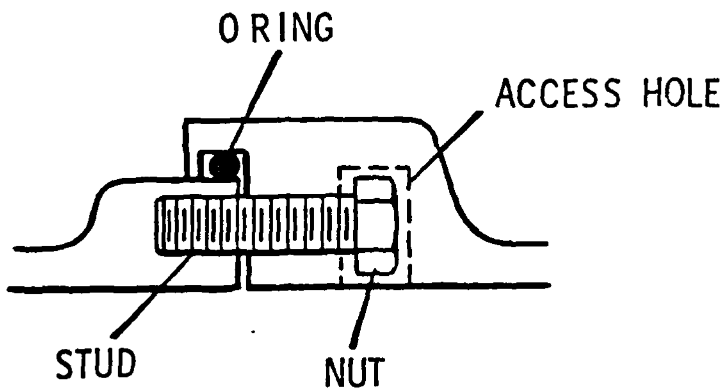


Figure 4. Sketch of Cross-Section of Joint Band

the length of each shell section. Each of the shell sections has five circumferential reinforcing ribs that are spaced between seven and eight inches apart as shown in Figures 1 and 2.

Sketches of the two endcaps are given in Figures 5 and 6. The instrumentation cables penetrate the endcap shown in Figure 5 and are attached to bars welded to the outside of the endcap.

In Figure 7, the double shell assembly is shown. The outer shell assembly consists of seven shells constructed of 16-gauge (0.05-in. thick) cold rolled steel. The diameter of the outer shells is 25 inches and the length of each shell is 36 inches. The space between the surfaces of the inner and outer shells is 2 inches and is free flooded. The height of the partitions that span between the outer shell and the outer surface of the inner shell is 2 inches, so that when the outer shells are installed, the partitions are in a tight metal-to-metal contact with the outer surface of the inner shell. The partitions are constructed of 16-gauge steel and spot welded to the outer shells with small L-shaped brackets. The partitions are located at every other inner shell rib position. Because the spacing of the inner shell ribs is not constant, the spacing of the partitions is also not constant.

A clam shell design was used on the outer shells so that they could be easily installed and removed. A piano hinge was used to attach the two halves of each shell. Angle irons were spot welded to both edges of each of the shell halves. The shell was opened, wrapped around the inner shell, and closed by bolting the angle irons together to form a tight fit around the inner shell. After installation around the inner shell assembly, the outer shells were attached to each other with screws around the perimeter.

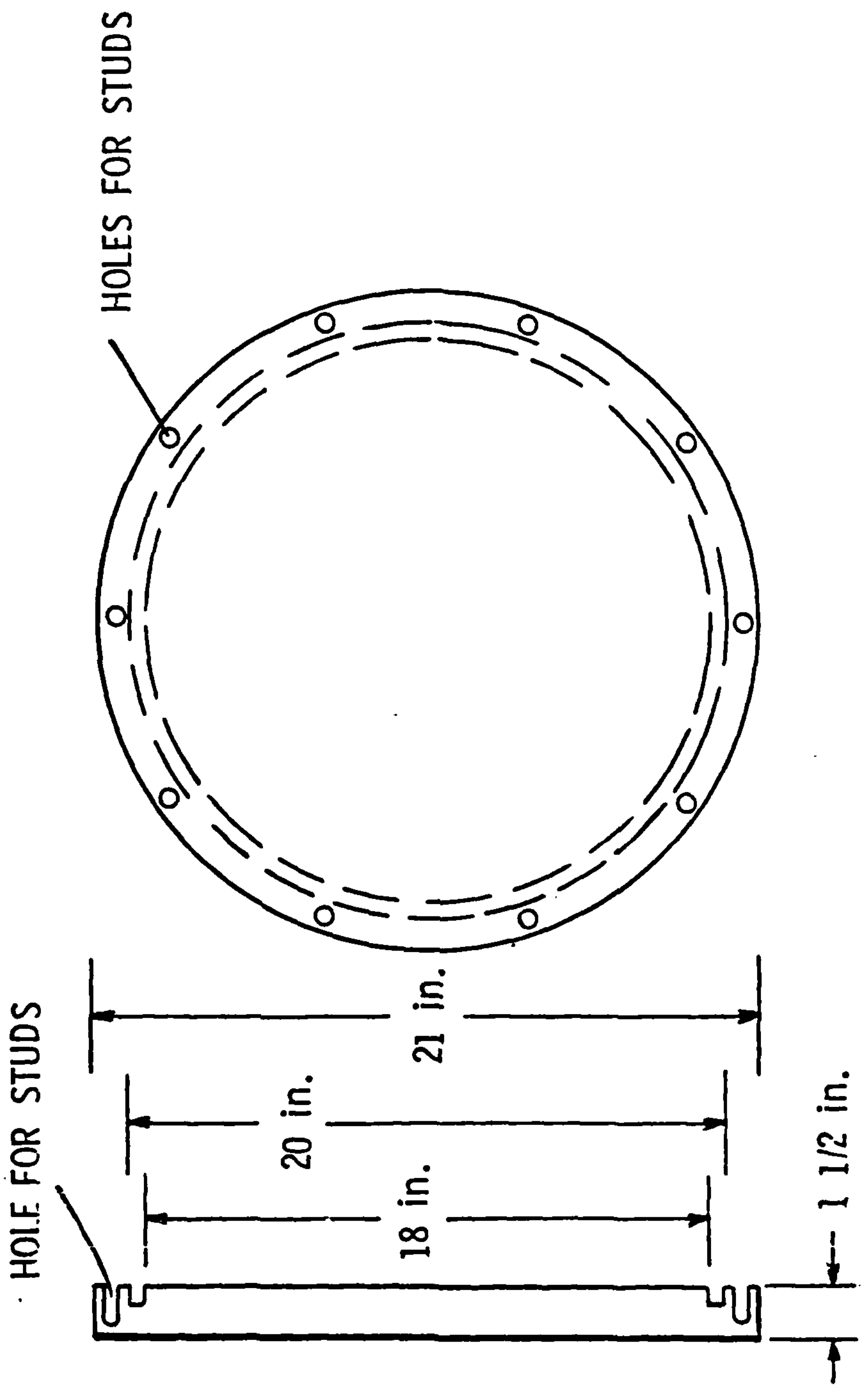


Figure 5. End Caps without Cable Penetrations

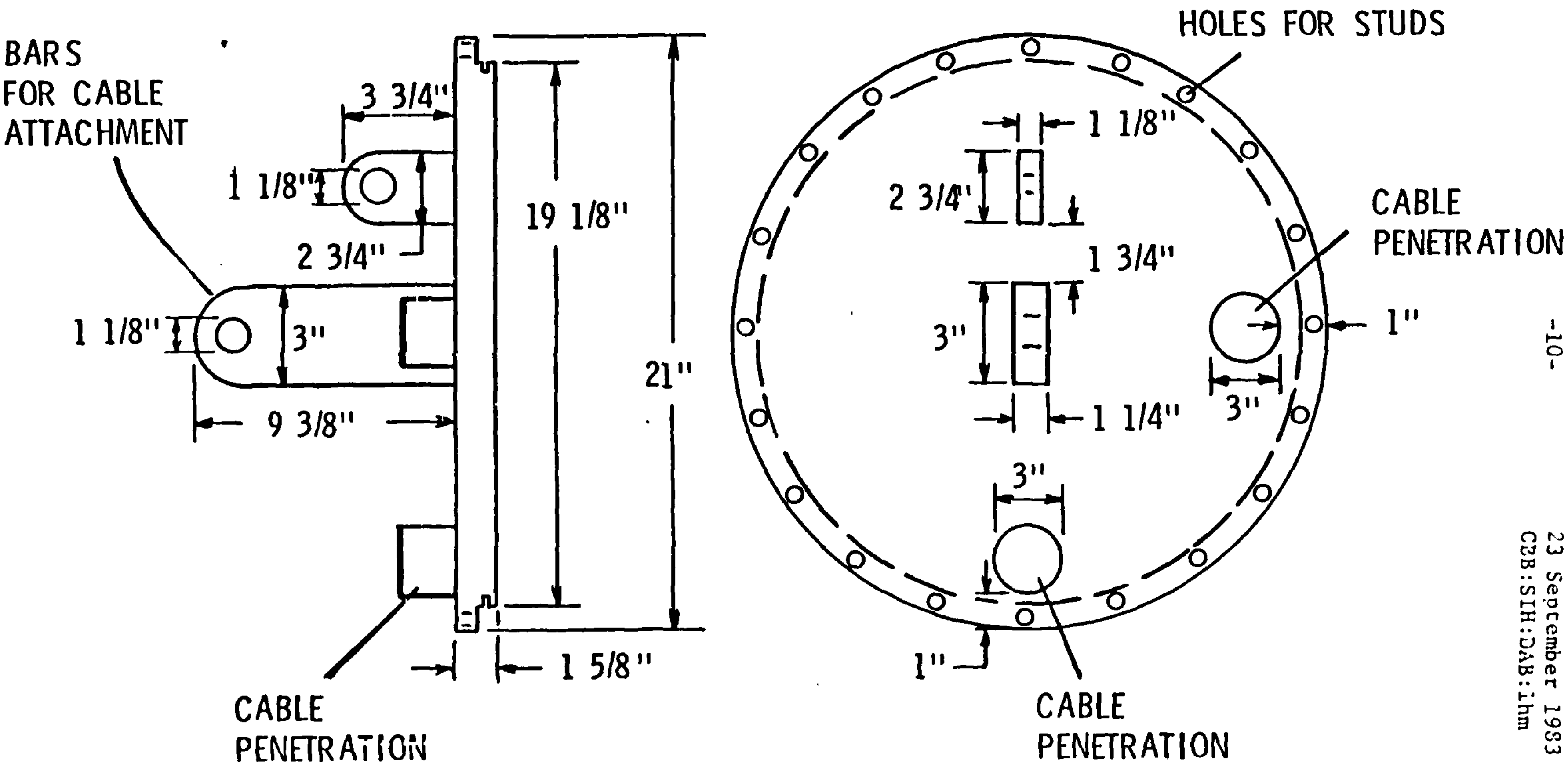


Figure 6. End Caps with Cable Penetrations

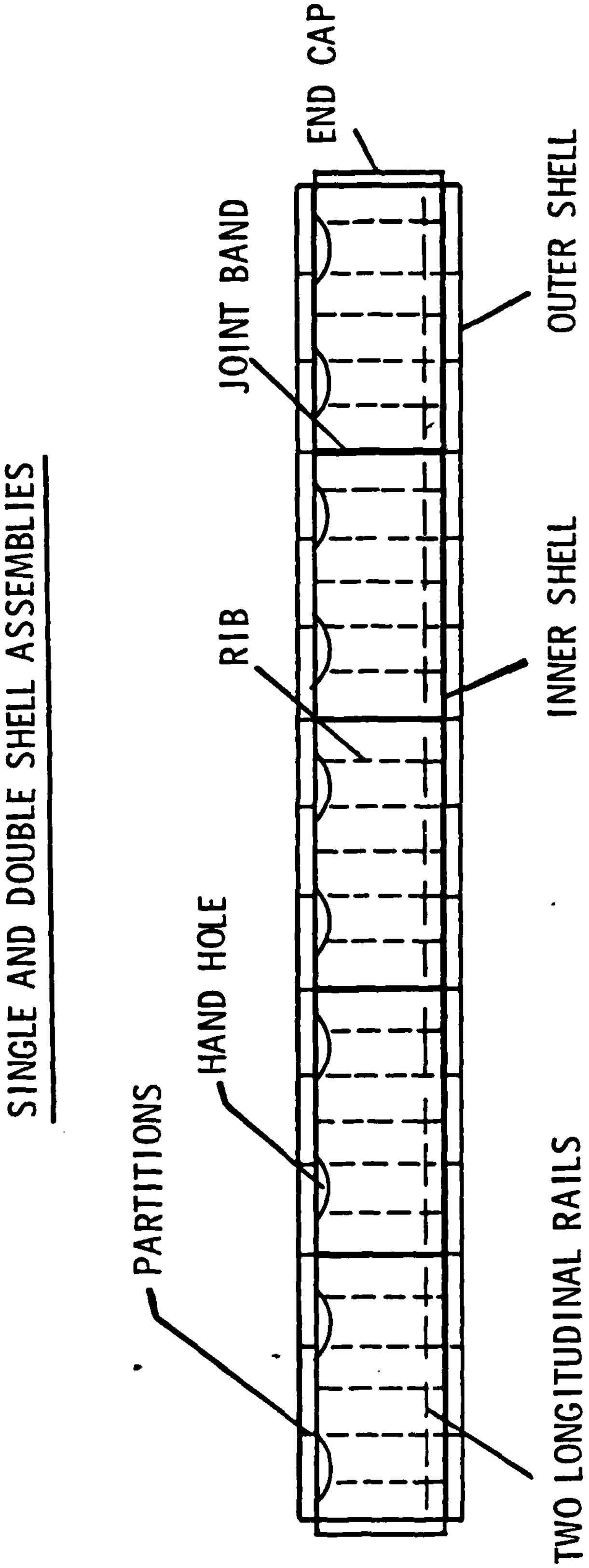


Figure 7. Single and Double Shell Configuration

2.2 Measurement Instrumentation

The locations of the accelerometers and shakers used to make the resonant measurements are shown in Figure 8. The accelerometers are BBN 501s which have internal preamplifiers to reduce cable noise, a frequency response of 4 to 20,000 Hz with a ± 5% maximum variation in sensitivity, and a nominal sensitivity of 10 mV/g. The sensitivity of each accelerometer was measured by ARL/PSU before installation inside the shell assembly. The accelerometers were glued with epoxy to flat spots ground into the inner surface of the inner shell.

Triaxial accelerometers were located at the base of the lower shaker at each of the three shaker locations as shown in Figure 8. These accelerometers were glued to 1/2-inch cubic aluminum blocks and the blocks glued as close to the base of the shaker mount blocks as possible with one accelerometer oriented radially, one oriented circumferentially, and one oriented axially.

The shakers were Wilcoxon F4 shakers with impedance heads. These shakers have a usable frequency range from 10 to 7,000 Hz. The force and accelerometer signals from the impedance head in each of the shakers were recorded along with the signals from the accelerometers. At shaker locations X and Z, the shakers were located on ribs. At these locations, the mounting block to which the shakers were attached via a stud is shown in Figure 9(a). At shaker location Y, the shakers were located on a joint band. At this location, the mounting block is shown in Figure 9(b). All of the mounting blocks were constructed of aluminum and welded to the shell. The four smaller taped holes were used to mount a bar for mounting the shakers for the moment drives used in the Lake Seneca measurements.

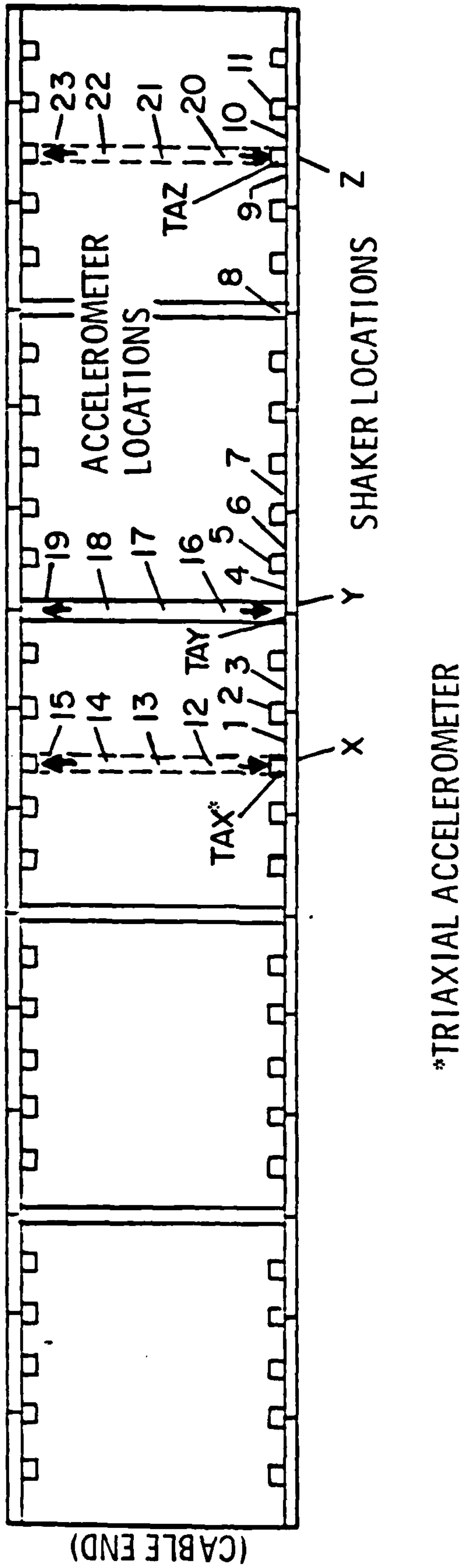


Figure 8. Shaker and Accelerometer Locations

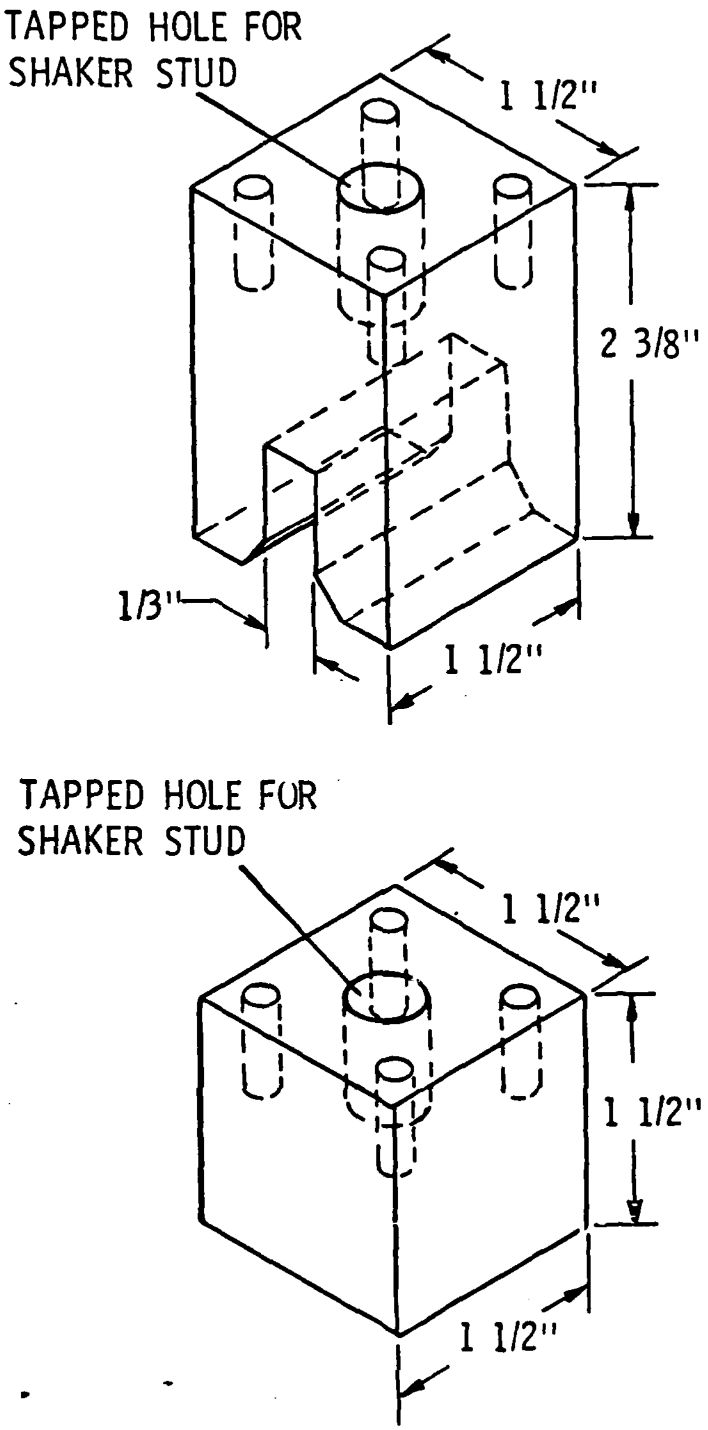


Figure 9. Shaker Mounting Blocks

Switching circuitry and preamplifiers were installed inside the shell assembly so that accelerometers, shakers and the gains of the preamplifiers could be remotely selected from the NUSC TCP during the field measurements at Lake Seneca where the shell assembly was 250 feet under water. The preamplifier gains could be changed in 6 dB steps. Since the distribution of the vibration levels, and not the absolute levels, are needed for determination of mode shapes, the gains were all set to the same value and held constant during all of the resonant measurements at ARL/PSU.

The signals from the accelerometers and impedance heads were transmitted through 11 preamplifiers inside the shell assembly before transmission to the operator's location through two 300-foot multi-conductor cables. Before recording on a 14-track Honeywell 1500C FM tape recorder, the signals were amplified by Ithaco 453 amplifiers. Two channels on the tape recorder were reserved for the hydrophones used to measure the farfield radiated noise at Lake Seneca. The 11 signals from the shell assembly were recorded on 11 channels on the tape recorder, with the remaining channel used to record the drive signal. The input record and output playback signals from selected channels on the tape recorder were displayed on an oscilloscope to check on the quality of the recorded data.

The drive signal was a pure tone generated by a Spectral Dynamics 104A sweep oscillator and amplified by a MacIntosh power amplifier. As data were recorded, the oscillator signal was swept automatically from 20 to 5,000 Hz at a logarithmic sweep rate, so that the sweep rate was lower at the lower frequencies and increased with frequency. Each frequency sweep took approximately five minutes.

In addition to recording the data for processing later, on-line measurements of the resonant frequencies were made by manually varying the frequency of the drive signal and observing the frequencies at which peaks in the vibration levels occurred . During these measurements, the vibration levels were displayed on a Ballantine voltmeter.

2.3 Measurement Configurations

A list of the resonant measurement configurations is given in Table 1. There are four shell configurations; single shell in air, single shell in water, double shell in air and double shell in water. Only radial drive shaker positions were used during the resonant measurements. The moment and circumferential drive positions used during the field measurements at Lake Seneca were not used during the resonant measurements at ARL/PSU. As indicated in Table 1, the shakers were operated in three modes; a single shaker (the lower shaker in Figure 8), both shakers in phase and both shakers out of phase. With the shakers in phase, both shakers are in phase in the radial direction and thereby excite the even numbered circumferential modes. With the shakers out of phase, the odd numbered circumferential modes were excited. These three modes of shaker operation were used at each of the three shaker locations; in the middle of the middle shell in the shell assembly (Shaker Location X), on the joint band at the end of the middle shell (Shaker Location Y), and in the middle of the end shell (Shaker Location Z). Therefore, resonant measurements were conducted for nine types of excitation, three modes of excitation at each of three locations for all four shell configurations for a total of 36 different resonant frequency measurements.

Table 1. Measurement Configurations

Meas. No.	Shell Type	Air or Water	Shaker Location*	Number of Shakers
1	Double	Air	X	Both-In Phase
2	Double	Air	Y	Both-In Phase
3	Double	Air	Z	Both-In Phase
4	Double	Air	X	Single
5	Double	Air	Y	Single
6	Double	Air	Z	Single
7	Double	Air	X	Both-Out of Phase
8	Double	Air	Y	Both-Out of Phase
9	Double	Air	Z	Both-Out of Phase
10	Single	Air	X	Both-In Phase
11	Single	Air	Y	Both-In Phase
12	Single	Air	Z	Both-In Phase
13	Single	Air	X	Single
14	Single	Air	Y	Single
15	Single	Air	Z	Single
16	Single	Air	X	Both-Out of Phase
17	Single	Air	Y	Both-Out of Phase
18	Single	Air	Z	Both-Out of Phase
19	Single	Water	X	Both-In Phase
20	Single	Water	Y	Both-In Phase
21	Single	Water	Z	Both-In Phase
22	Single	Water	X	Single
23	Single	Water	Y	Single
24	Single	Water	Z	Single
25	Single	Water	X	Both-Out of Phase
26	Single	Water	Y	Both-Out of Phase
27	Single	Water	Z	Both-Out of Phase
28	Double	Water	X	Both-In Phase
29	Double	Water	Y	Both-In Phase
30	Double	Water	Z	Both-In Phase
31	Double	Water	X	Single
32	Double	Water	Y	Single
33	Double	Water	Z	Single
34	Double	Water	X	Both-Out of Phase
35	Double	Water	Y	Both-Out of Phase
36	Double	Water	Z	Both-Out of Phase

*See Figure 8

There were only 11 channels available in the instrumentation package inside the shell for the transmission of data from sensors inside the shell assembly to the tape recorder. Therefore, data were not recorded for all of the accelerometers shown in Figure 8. The accelerometers for which data were recorded are listed in Table 2 for each of the three shaker locations. Not listed in Table 2 are the force and acceleration from the impedance heads of the operating shakers and the triaxial accelerometer near the lower of the operating shakers, which were recorded during all of the resonant measurements. The accelerometers listed in Table 2 are the same accelerometers for which data were taken at Lake Seneca. In order to record data from all of the accelerometers listed in Table 2, as well as the drive signal, the signals from the impedance heads of the active shakers, and the signals from the triaxial accelerometer near the lower of the active shakers, two recordings were made for each measurement configuration. The force from the active shakers and the drive signal were recorded during both recordings. Because of the time required to make the on-line resonant frequency measurements manually, on-line data were taken for only a few of the sensors listed in Table 2. These are denoted in Table 2 by asterisks.

2.4 Data Acquisition and Reduction

2.4.1 On-Line Measurement

During the field measurements at Lake Seneca, acoustic radiation patterns were measured at selected resonant frequencies. Therefore, before taking the shell assembly to Lake Seneca, on-line data were taken on resonant frequencies at ARL/PSU to determine the resonant frequencies that could be used in the measurements of the radiation patterns.

Table 2. Accelerometers from which Data were Recorded

Shaker Location	Recorded Accelerometers
X	Accel. Nos. 1*, 2*, 3, 4, 5, 6, 8, 9*, 10*, 12, 13, 14*, 15*
Y	Accel. Nos. 1, 2, 3, 4*, 5*, 6, 7, 8, 9*, 16, 17, 18*, 19*
Z	Accel. Nos. 1*, 2*, 4, 5, 7, 8, 9*, 10*, 11, 20, 21, 22*, 23*

*Sensors for on-line resonant frequency measurements

The method of obtaining the on-line resonant frequency data was simple. For each type of excitation, the acceleration levels from selected accelerometers (those denoted with an asterick in Table 2) were observed on a voltmeter as the frequency of the shaker drive signal was varied manually. When the observed level reached a maximum, the frequency of the drive signal was read from frequency counter and recorded. Above 1,000 Hz, it became difficult to separate resonant frequencies, because the modal density was high enough that the overlap of modes was sufficient to prevent the separation of all resonant modes. Therefore, data on resonant frequencies are not reproted above 1,000 Hz.

All of the on-line resonant frequency data were arranged in numerical order and the frequencies that appeared only a few times were removed. Frequency values that were within the measurement uncertainty of ± 2 Hz were grouped together and the averages of the data in each group taken so that only the frequencies that are clearly resonant are reported. For all of the 36 measurement configurations, these averages are given in the Appendix for the eight or nine accelerometers used in each measurement.

The increase in model density with frequency, mentioned above, does not shown in the data given in the Appendix because as the frequency increased modal overlap increased, thereby decreasing the number of distinct resonant frequencies that could be found.

2.4.2 Off-Line Measurements

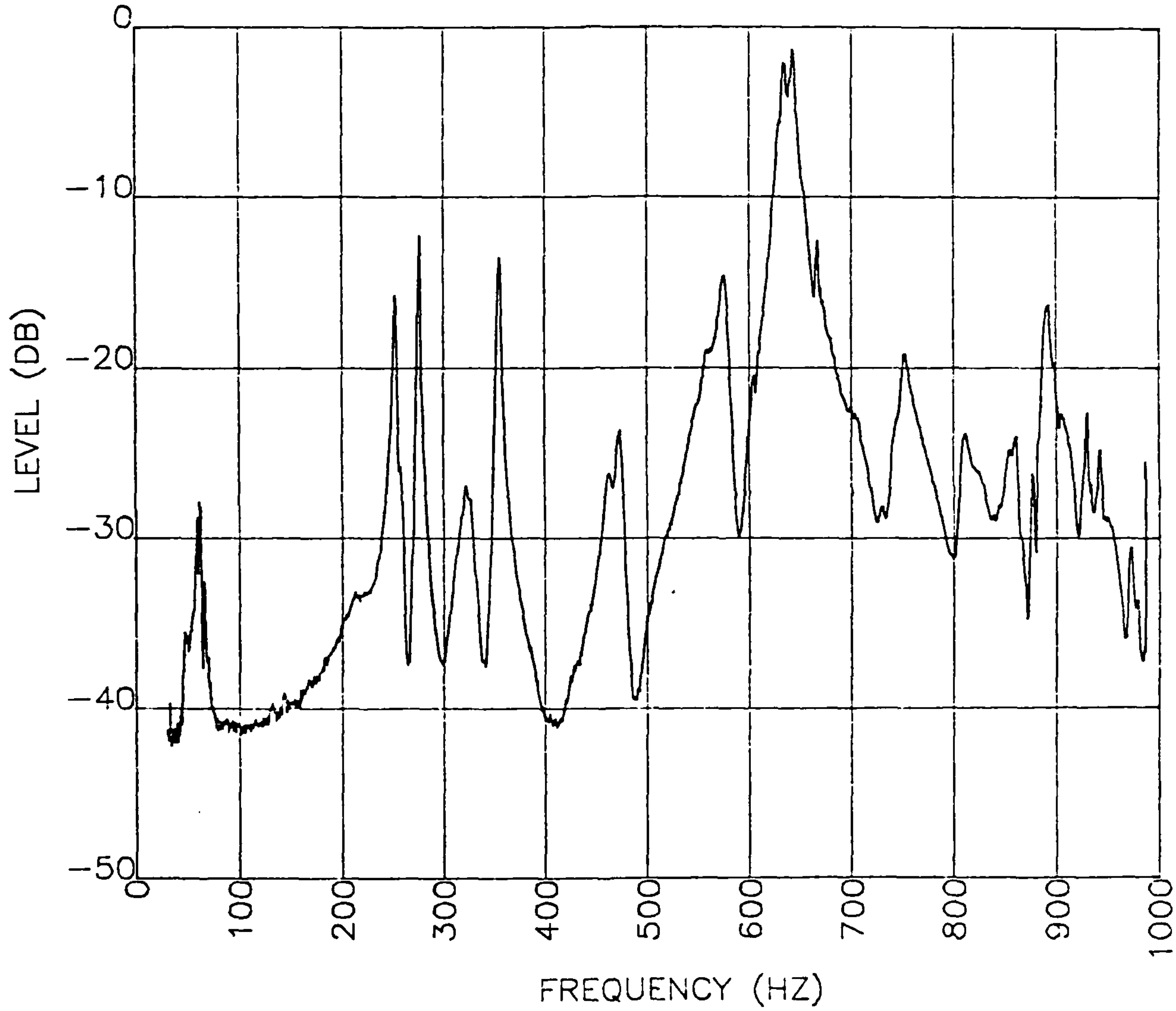
In addition to the on-line measurements discussed above, data were recorded during frequency sweeps from 20 to 5,000 Hz. During playback, the 11 channels which contained signals from sensors inside the shell were plugged into logarithm-to-linear detectors which converted the playback

signals to DC voltages proportional to the logarithmic level of the playback signal, where a 10 dB change in level produced a 1 volt change in detector output. The recorded shaker drive signal was converted from an analog signal to a DC voltage proportional to the frequency of the signal. The frequency range from 0 to 1 kHz was converted to voltages ranging from - 5 to + 5 volts.

The DC voltages from all channels were sequentially digitized at a rate of 20 samples per second by a 10-bit multichannel analog-to-digital convertor. With 10 bits, the number of possible digital values to cover the 1 kHz frequency range is 1022 (one bit is used for the sign). Therefore, the maximum frequency resolution in the digitized frequency data is 1 Hz, so that as the frequency of the analog signal increased, the digital data jumped in 1 Hz steps. Near the frequency steps, the digital data hunted for the correct frequency, jumping back and forth between bins. Before plotting, the digital frequency was smoothed to provide a smooth plot and, more importantly, to increase the frequency resolution to less than 1 Hz. Since the drive frequency increased monotonically with time, a running average of the frequency was used to smooth the frequency data. Seventy data points were used in the running average.

The digital data was recorded on digital tape for storage. A computer program was written to read, process and plot the digital data. Corrections to the data were made for differences in the sensor sensitivities and amplifier gains, so that levels from different sensors could be compared.

The corrected data was then plotted on a digital plotter. As shown by the sample plot in Figure 10, the measurement number, shell configuration, sensor and shaker location and phase between shakers are labeled on each plot. The measurement number refers to the number in Table 1.



PLOT FOR ONR LAB MEASUREMENT NO. 013 CUT NO. 2
SINGLE SHELL IN AIR
ACCELEROMETER NO. 1
SHAKER LOCATION – MIDDLE OF SHELL
SINGLE SHAKER

Figure 10. Example of Data Plot

The resonant mode shapes were determined by plotting the levels at a resonant frequency as a function of position on the shell for each of the nine shaker configurations. Plots were made along the circumferential line at the shaker location and along the axial line from the lower shaker location in the middle of the shell assembly. Sample plots are shown in Figure 11 through 14. It should be noted in these sample plots that the density of the accelerometers is too small to permit a detailed description of the mode shape. Therefore, it was not possible to identify the shapes of the higher order modes.

3. Analysis

The identified resonant frequencies for the four shell configurations, presented in Table 3, are taken from the data given in the Appendix.

With the exception of the triaxial accelerometers located below the lower of the active shakers, all of the accelerometers are oriented radially. For each measurement, data was taken from only one accelerometer oriented in the circumferential direction and one in the axial direction. Therefore, from the measurement data, it is not possible to identify mode shapes for resonant frequencies of torsional or longitudinal modes of vibration. Only resonant frequencies for bending moes, where the motion is largely radial, can be identified from the measurement data.

At the higher frequencies, the density of the resonant frequencies increase, such that modal overlap made it difficult to identify all resonant frequencies. Therefore, above 500 Hz, it is unlikely that all of the resonant frequencies are given in Table 3. Below 400 Hz, only lower-order resonant modes are present so that the resonant frequencies

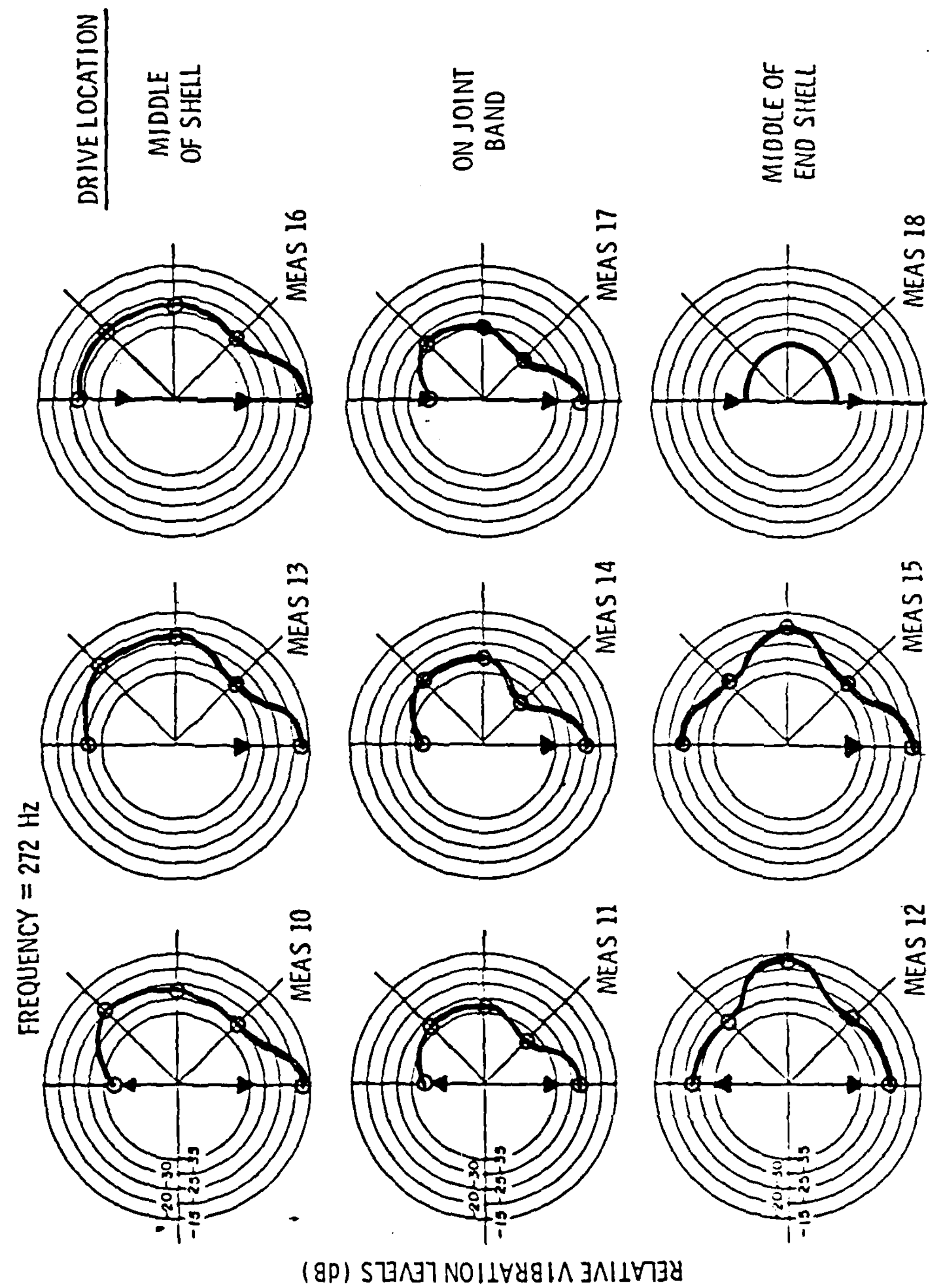


Figure 11. Example of Circumferential Mode Plot

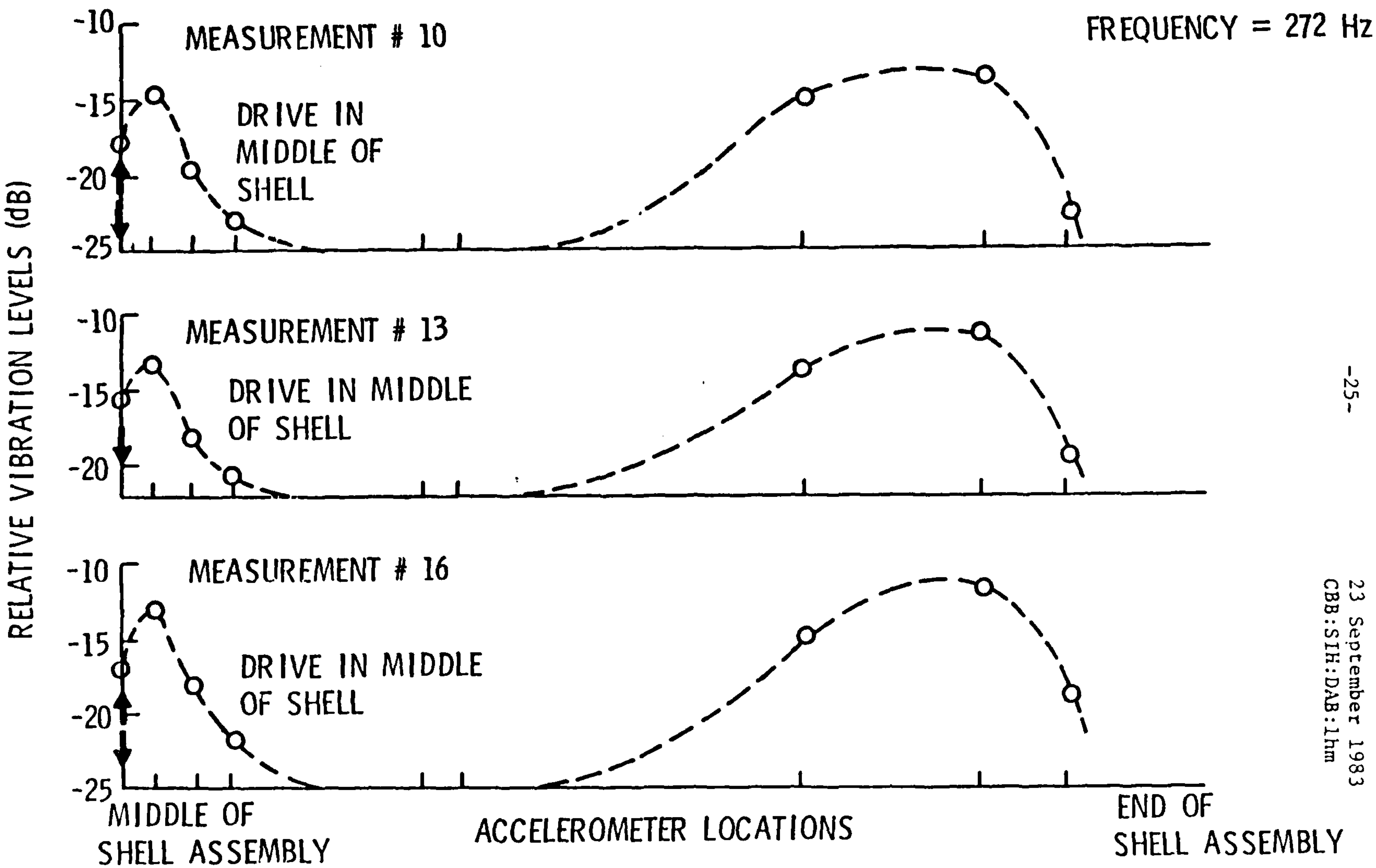


Figure 12. Example of Axial Mode Plot with Shaker in Middle of Shell

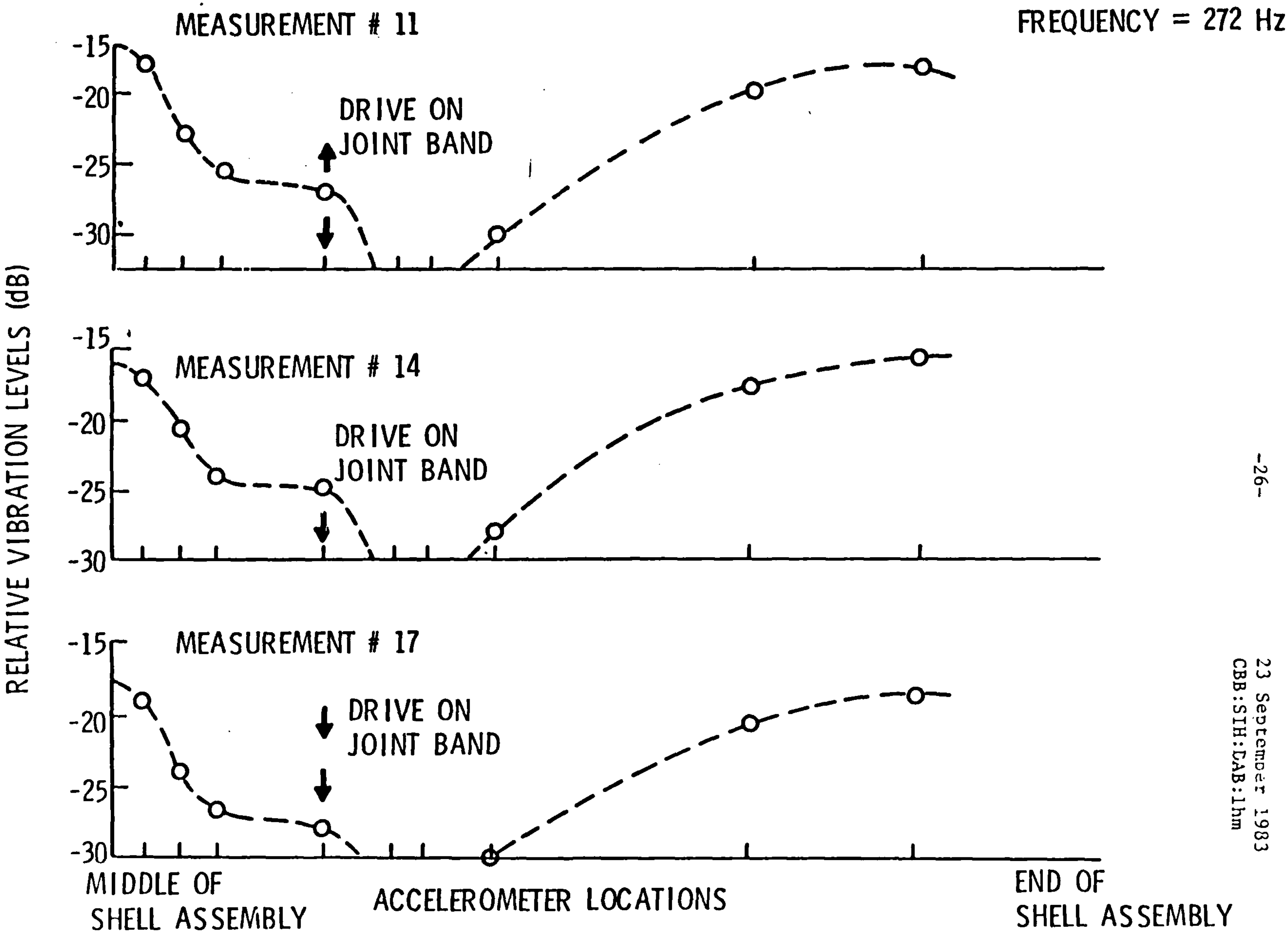


Figure 13. Example of Axial Mode Plot with Shaker on Joint Band

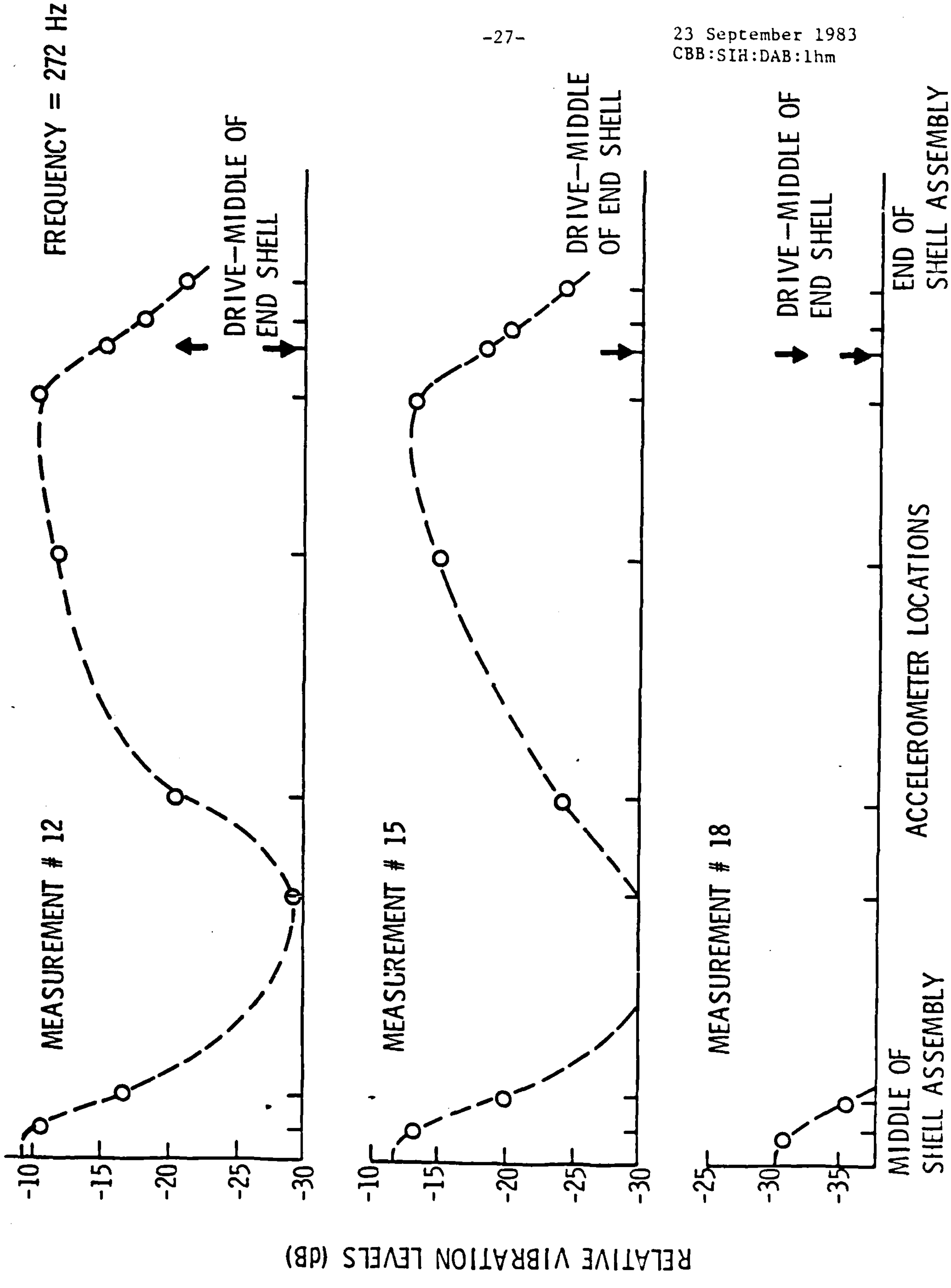


Figure 14. Example of Axial Mode Plot with Shaker in the Middle of the End Shell

Table 3. Identified Resonant Frequencies

Single Shell, In-Air	Single Shell, In-Water	Double Shell, In-Air	Double Shell, In-Water
41	57	54	47
53	140	58	142
57	145	133	164
130	156	236	185
245	166	246	195
252	176	249	217
263	187	254	282
272	255	263	301
334	273	268	423
352	325	313	438
389	335	322	519
408	340	347	597
422	370	351	669
428	381	360	754
467	386	378	767
548	444	383	
575	467	388	
616	472	482	
635	503	538	
639	576	548	
646	603	602	
697	648	614	
743	691	627	
761	716	638	
806	778	647	
827	782	660	
844	789	673	
874	793	689	
905	829	695	
918	832	711	
928	866	721	
944	869	729	
958	894	753	
985	913	772	
987	920	785	
990	934	795	
	975	803	
		871	
		879	
		886	
		891	
		934	

were separated enough that it is likely that all of the resonant frequencies for the bending modes below 400 Hz are identified in Table 3.

As observed in Table 3, the number of resonant frequencies identified for the double shell in water is lower than the number identified for the other three shell configurations. There are no resonant frequencies identified above 800 Hz for the double shell in water. As illustrated in Figure 15, comparison of the measured shell responses for the single and double shells in water show that the double shell reduces the responses at resonant frequencies. Thus, it appears that the double shell provides additional damping to the single shell which increases the modal overlap of the resonant modes, decreasing the number of resonant frequencies that could be identified, particularly at the higher frequencies. The damping effect of the double shell also occurs when the shells are in air, as illustrated in Figure 16.

Observation of data in Figure 15 indicates that adding the outer shells in water increases the resonant frequencies. For example, note the peak that occurs around 400 Hz for the single shell increased when the outer shells were added. This implies that when in water, the stiffness added by the outer shells has more effect than the mass added by the outer shells. However, the resonant frequencies do not appear to increase when the outer shells are added in air; see Figure 16.

Observation of the resonant frequencies in Table 3 indicates that the resonant frequencies in air are higher than those in water. The group of resonant frequencies for the single shell in air between 245 and 272 Hz appears to have shifted down to frequencies between 140 and 166 Hz when the shell was placed in water. Comparison of the response of the single shell in air to the response of the single shell in water show a significant reduction

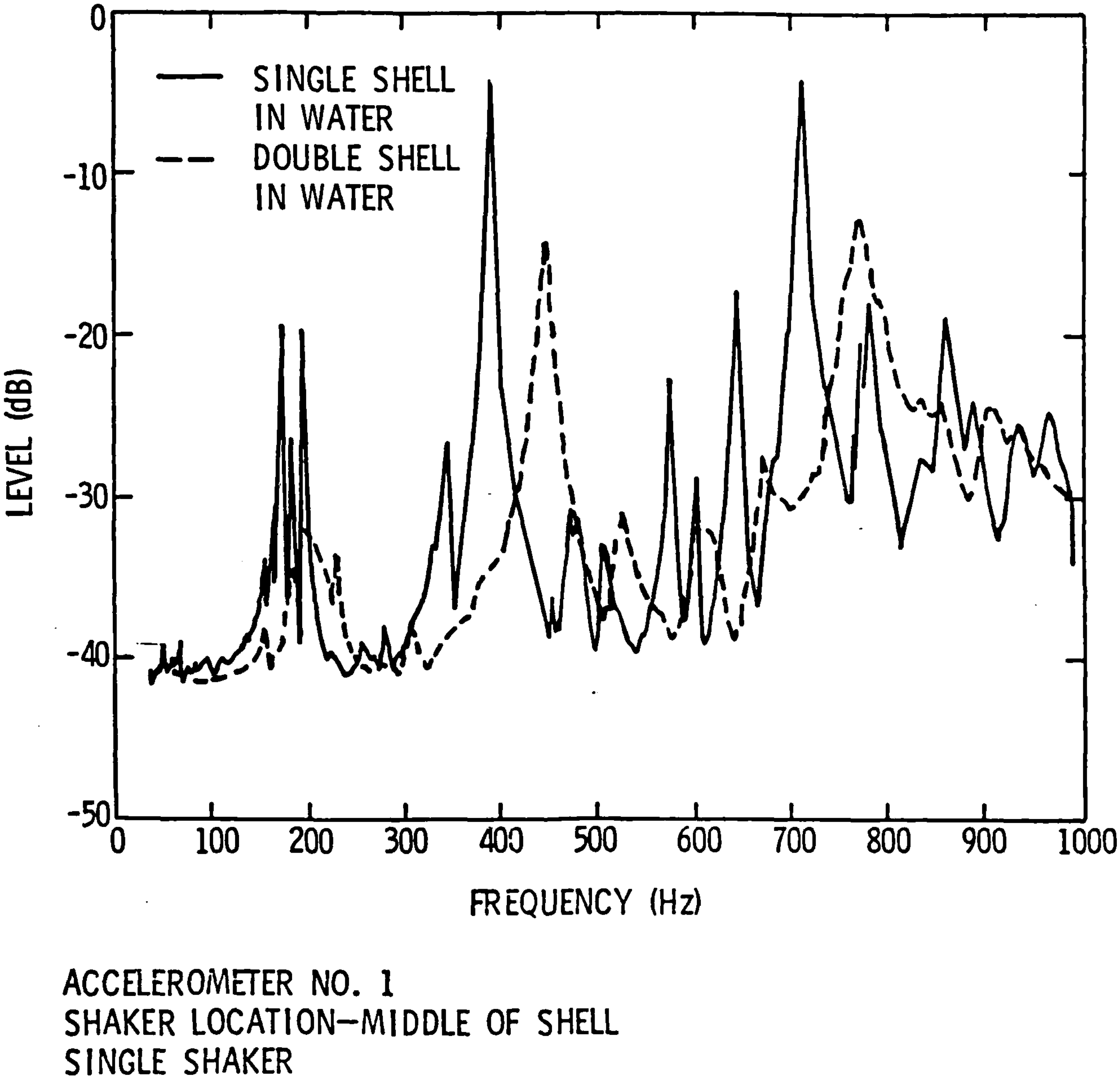
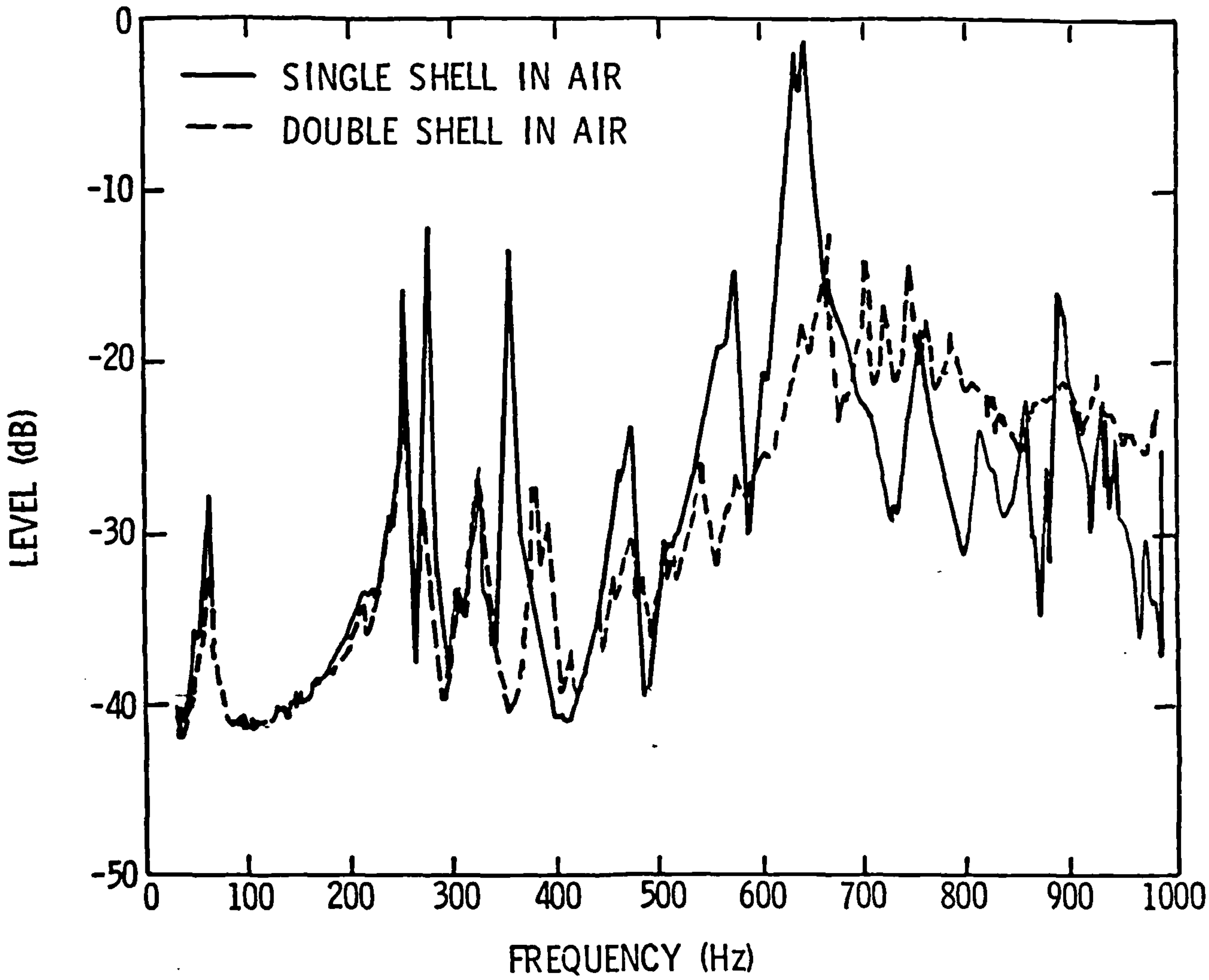


Figure 15. Comparison of Single and Double Shell Vibration Responses in Water



ACCELEROMETER NO. 1
SHAKER LOCATION—MIDDLE OF SHELL
SINGLE SHAKER

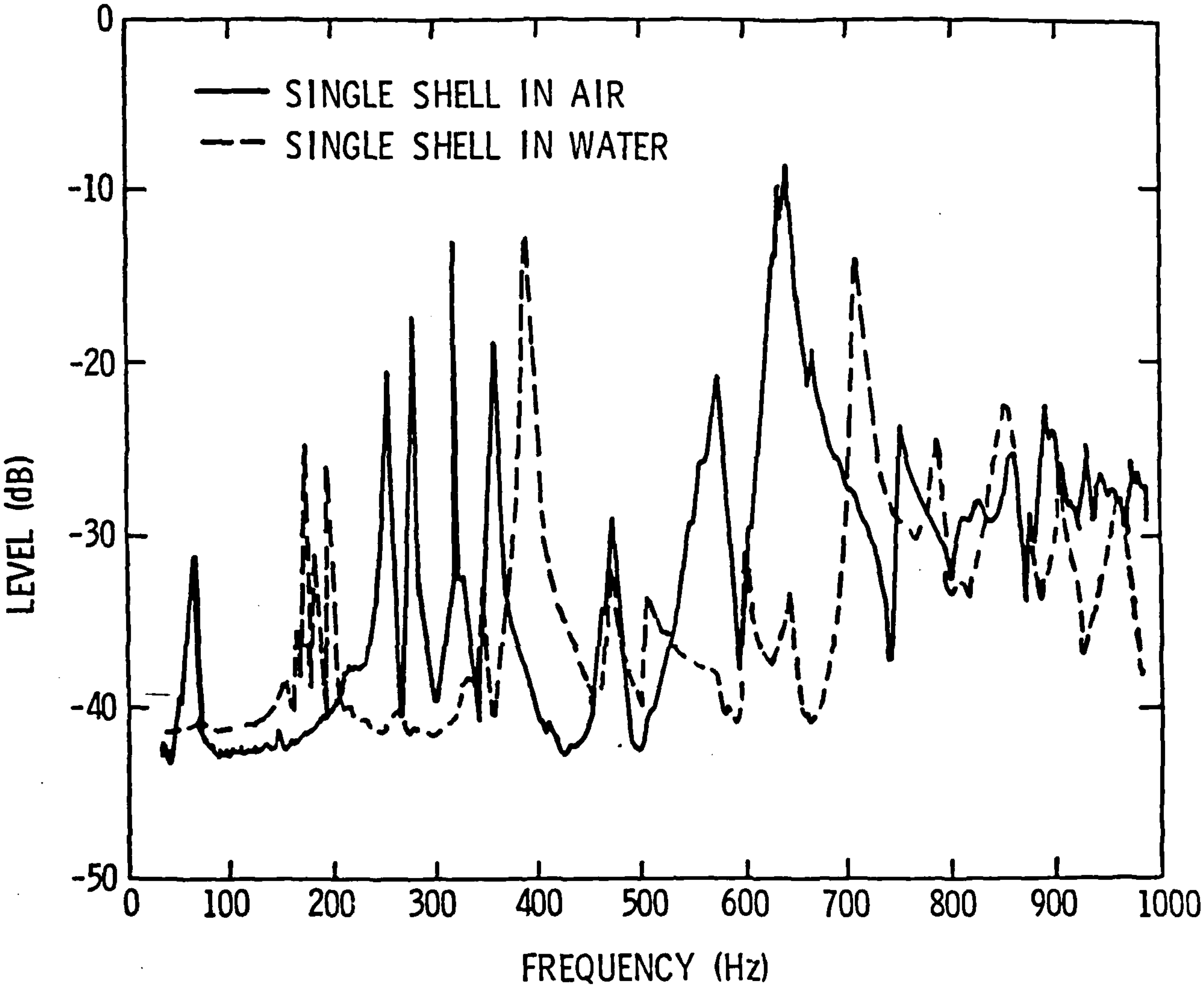
Figure 16. Comparison of Single and Double Shell Vibration Responses in Air

in the frequencies at which peaks in the response occur. This reduction in resonant frequencies, when the shell is in water, is illustrated in Figure 17. In addition to reducing the resonant frequencies, the water also provides some additional damping, as shown in Figure 17.

The effects of the double shell, which damps the resonant response of the single shell, and water, which reduces the frequencies at which a given resonant mode occurs and provides some additional damping, combine to decrease the number of resonant frequencies that have been identified in Table 3.

For the lower resonant frequencies, the modes of vibration were identified by constructing plots of the vibration levels as a function of accelerometer position inside the shell. The method of identifying the mode shapes for the lower resonant frequencies is illustrated by observing the sample plots given in Figures 11 through 14 for the single shell in air at 272 Hz. Data on the phase between accelerometers was not retained in the data processed so that only the amplitude of the vibration levels in dB are plotted in Figures 11 through 14.

The mode number in the axial direction is determined by observing the data in Figures 12 through 14, where the vibration levels are plotted at each of the accelerometer positions along the shell axis. These accelerometer positions are denoted by a mark along the lower axis in each plot. No data are shown at accelerometer positions where the peaks in the measured levels did not occur at 272 Hz. One-half of the shell assembly is covered by the data in Figures 12 through 14. In all of the plots in Figures 12 through 14, the data show peaks near the middle of the shell and about one-third from the end of the shell, with one null in between the two peaks and one at the end of the shell. Thus, there appears to be



ACCELEROMETER NO. 2
SHAKER LOCATION—MIDDLE OF SHELL
SINGLE SHAKER

Figure 17. Comparison of Single Shell Responses in Air and in Water

three-fourths of a wavelength between the middle and end of the shell assembly. This indicates an axial mode number of m = 3, which is the number of half-wavelengths along the length of the shell assembly.

In the circumferential direction, the mode number is determined by observing the vibration levels plotted in Figure 11. With the shakers in the middle of the end shell, the data in Figure 11 show two nulls at ± 45° from the horizontal and peaks in the horizontal direction and in the up and down vertical directions. This indicates one wavelength around one-half of the shell circumference, which corresponds to an n = 2 circumferential mode.

With the shakers in the middle of the shell or on the joint band, the circumferential mode shape is not as clear as when the shakers were in the middle of the end shell. The levels for the accelerometer in the up vertical position are lower and the levels at 45° above horizontal are higher than expected for an n = 2 circumferential mode. This is probably caused by the constraining forces applied to the shell at the joint bands by the hoist cables from which the shell was hung during the in air measurements. These constraining forces may also explain the modal response of the shell when the shakers in the middle of the shell and on the joint band are out-of-phase. With the shakers out-of-phase, only the odd-numbered circumferential modes should be excited. The constraining forces are near the upper shaker, which could result in a smaller shell response near the upper shaker than the response near the lower shaker, so that, although the excitation is out-of-phase, the amplitude of the responses near the two shakers are not equal. Therefore, the n = 2 circumferential mode could be excited when the shakers are out of phase in the middle of the shell or on the joint

band. When the shakers are in the middle of the end shell, away from the constraining forces, the n = 2 circumferential mode is not excited when the shakers are out-of-phase as shown in Figures 11 and 14.

In order to account for the constaining forces applied by the hoist cables, the static "spring constant" of the hoist cables was measured by hanging weights on the end of the cables and measuring the displacements. The hoist configuration was similar to the configuration used to hang the shell assembly. It included the polyurethane coated brackets to which the shell was attached and the deflection of the overhead rails to which the hoists were attached. The measured spring constant is 6300 lb/in.

In addition to the constraining forces applied by the hoist cables, 1250 lb weights were hung from the shell joint bands at the two locations opposite the cable attachment points during the in water measurements to provide negative buoyancy. However, because the constraining forces for the in-water measurements are opposite to each other, the affect on the n = 2 circumferential mode shape is smaller than for the in-air measurements where the constraining forces were applied only to the top of the shell.

The in-water resonant measurement configuration was similar to that used at Lake Seneca for the acoustic radiation and scattering measurements. Thus, the results from the in-water resonant measurements can be applied to the analysis of the measurement data taken at Lake Seneca, particularly the acoustic radiation data which were taken at frequencies low enough that the resonant response of the shell will be significant in the shell vibration and acoustic radiation.

The modes that were identified from plots of the vibration levels, similar to those illustrated in Figure 11 through 14, are presented in Table 4. For the single shell in air, eight modes were identified.

Table 4. Identified Mode Shapes

Mode No.		Shell Configuration			
n	m*	Single in Air	Single in Water	Double in Air	Double in Water
1	1	53, 57	57	54, 58	---
1	2	130	---	133	---
1	3	252	---	254	---
2	1	245	---	236	---
2	2	263	140	---	164
2	3	272	145	249	---
2	4	334	---	313	---
2	5	352	187	---	217

n = circumferential mode number

m = axial mode number

Because of the damping effects of water and the outer shells, it was not possible to identify the frequencies for all of the eight modes for the single shell in water or the double shell in air or in water. For the double shell in water, the damping was high enough that only two modes could be identified from the measured data.

The reduction in the resonant frequencies, when the shells are in water, indicated by the results in Table 3, are shown in Table 4. The ratio of the resonant frequencies for the single shell in water to the frequencies in air is 0.53 for all of the n = 2 circumferential modes. That is, the water reduces the resonant frequencies for the single shell by almost one half. The reduction in the resonant frequencies in water is due to the virtual mass of the surrounding water which tends to lower the resonant frequencies.

When the shells are in air, adding the double shell decreases the resonant frequencies for the n = 2 circumferential modes, however, the double shell has little effect on the resonant frequencies for the n = 1 circumferential modes in air. In water, the few resonant frequencies that are given in Table 4 imply that adding the double shell increased the resonant frequencies.

For the single and double shells in air, two frequencies are given in Table 4 for the lowest n = 1, m = 1 mode. At first, it appears that these two frequencies are associated with a split mode that is associated by a lack of shell symmetry in the circumferential direction that produces differences in the beam mode (n = 1) shell stiffness to vertical and horizontal beam motion. However, because the shakers are located along the axis of the shell symmetry, the horizontal beam mode would not be exicted directly. The plots in Figures 18 and 19 show that there is no modal response at the horizontal accelerometers at both 53 and 57 Hz for the single shell in air. The data for the double shell in air at 54 and 58 Hz

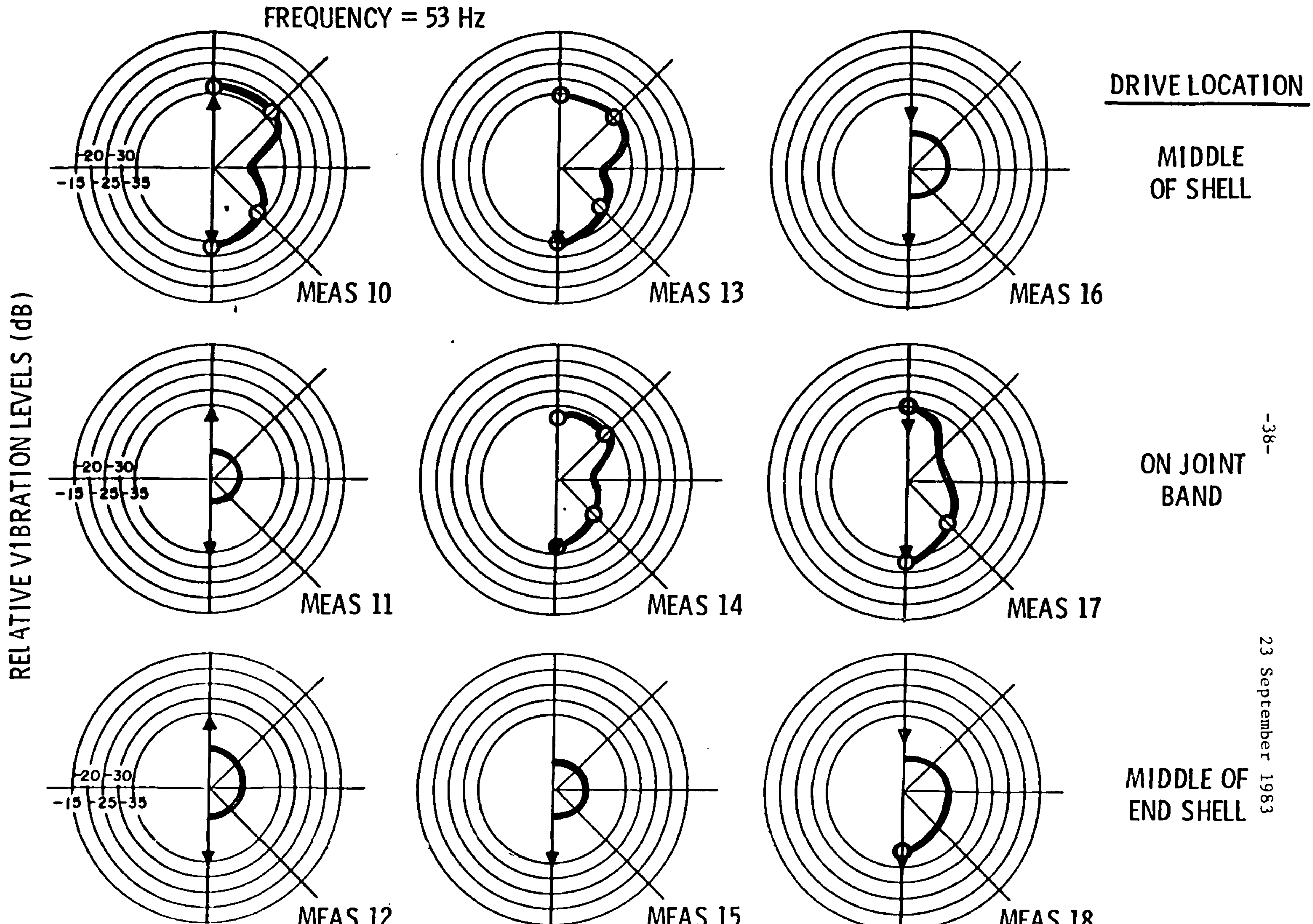


Figure 18. Circumferential Mode Plots for [illegible] Shell in Air at 53 Hz

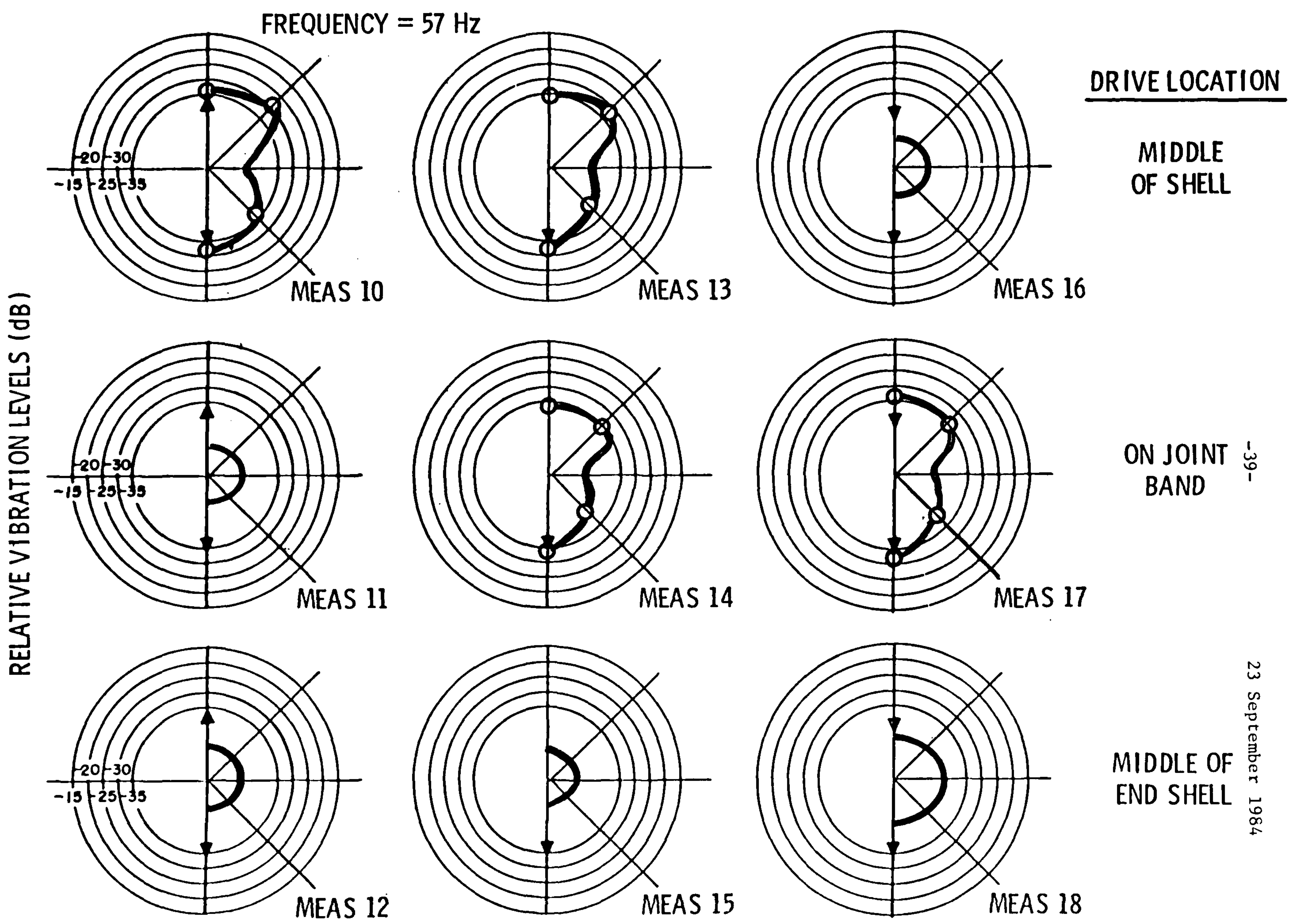


Figure 19. Circumferential Mode Plots for Single Shell in Air at 57 Hz

are similar to the data presented in Figures 18 and 19. This implies that the two lowest resonant frequencies for the single and double shells in air are not split beam modes, since, if these frequencies were a split mode, then there would be a modal response in the horizontal direction at one of the two frequencies.

Acknowledgment

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APPENDIX: ON-LINE RESONANT FREQUENCY DATA

In this appendix, the resonant frequency data taken on-line are presented for the 36 resonant frequency measurements. In the following tables, SX_1 (SX_2) refer to the accelerometers in the impedance head of the lower (upper) shaker at shaker location X, and TAX(1Y) refers to the triaxial accelerometer at the shaker location X in the circumferential direction (1Y). The axial direction is denoted by 1Z.

Table A1. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, In-Phase Located in the Middle of the Shell

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
53	53	53	53	53	53	----	----	----
57	57	57	57	57	57	----	----	----
245	245	245	245	245	----	----	----	----
----	----	----	----	----	----	----	252	----
----	----	----	----	----	----	----	263	----
272	----	272	272	272	272	272	----	----
575	575	575	575	----	575	575	575	----
----	----	----	----	----	635	633	----	----
----	----	----	----	----	639	639	----	----
646	646	646	646	646	----	----	646	----
743	----	----	----	----	743	----	----	----
761	----	761	----	----	----	----	----	----
----	----	----	----	806	806	----	----	----
----	----	----	----	827	----	----	----	----
844	844	844	----	----	----	----	844	844
----	----	874	874	----	874	874	874	----
905	905	905	----	----	905	905	----	----
----	----	----	----	918	918	918	----	----
----	----	----	944	----	----	944	----	----
----	----	----	958	----	----	958	----	----
----	----	----	987	987	----	987	----	----

Table A2. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, In-Phase Located on the Joint Band

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
----	130	----	----	----	----	----	----	----
245	245	245	245	245	245	245	----	245
252	----	252	----	----	----	----	----	----
272	----	----	272	----	272	----	----	----
334	334	334	334	----	334	334	----	----
352	352	----	----	----	----	----	----	----
389	----	389	389	----	----	389	----	----
408	----	408	408	----	----	408	----	----
422	422	422	422	422	422	422	----	----
----	428	----	----	----	428	----	----	----
467	467	467	467	----	467	467	----	467
548	548	548	----	----	548	----	----	----
616	616	616	616	----	----	616	----	----
----	----	----	----	----	635	----	----	----
----	-----	----	----	----	639	----	----	----
743	----	743	743	743	----	743	----	----
827	827	827	827	827	827	827	----	----
----	----	----	----	874	----	874	----	----
905	----	----	----	905	905	905	----	----
----	----	----	----	----	----	918	----	----
----	928	----	----	----	928	----	----	----

Table A2. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, In-Phase Located on the Joint Band (Continued)

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
944	----	----	----	----	----	----	----	----
958	958	----	----	----	958	----	----	----
985	----	----	----	----	----	----	----	----
----	----	----	----	----	990	----	----	----

Table A3. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, In-Phase Located in the Middle of the End Shell

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
41	----	----	----	----	----	41	----	----
----	245	----	----	245	245	245	----	----
----	252	----	----	----	----	252	----	252
263	263	263	263	----	263	----	----	----
272	272	272	272	272	272	272	----	272
334	334	334	334	----	----	----	----	----
352	352	352	352	352	352	352	352	----
----	389	----	----	389	----	----	----	----
----	408	----	----	----	----	----	----	----
422	422	422	----	----	----	----	----	----
428	428	428	----	428	----	----	----	----
467	467	467	467	----	467	467	----	----
----	548	----	----	----	548	548	----	----
575	----	----	575	----	----	----	----	----
635	635	----	635	635	635	----	----	----
----	639	639	639	639	639	639	----	----
----	----	----	----	----	761	----	----	----
806	806	806	----	----	----	----	----	----
----	844	----	----	----	844	844	----	----
----	----	----	----	----	905	----	----	----
----	----	----	----	----	987	987	----	----

Table A4. Resonant Frequencies for Single Shell, In-Air with Single Shaker Located in the Middle of the Shell

Accelerometers							
SX_1 (Hz)	A1 (Hz)	A2 (Hz)	A15 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
53	53	53	53	53	----	----	----
57	57	57	57	----	----	----	----
245	245	245	245	----	----	----	----
252	----	----	252	----	----	252	----
272	272	272	272	272	272	----	----
352	352	352	352	352	352	----	----
467	467	467	467	467	467	----	467
575	575	575	575	575	575	----	----
----	----	----	----	635	----	----	----
----	----	----	----	639	639	639	----
646	646	646	646	----	----	----	----
743	----	----	----	----	----	----	----
761	----	761	----	----	----	----	----
844	844	----	----	----	----	----	----
----	----	----	----	874	----	----	----
905	905	----	905	905	905	----	----
----	----	----	----	----	944	----	----

Table A5. Resonant Frequenices for Single Shell, In-Air with Single Shaker Located on the Joint Band

Accelerometers							
SY_1 (Hz)	A4 (Hz)	A5 (Hz)	A19 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
53	53	53	53	53	----	----	----
57	57	57	57	----	----	----	----
130	130	130	130	----	----	----	----
245	245	245	----	----	----	----	245
252	252	252	----	252	----	252	----
272	----	----	----	272	272	----	----
334	334	334	334	334	334	----	----
352	----	----	----	----	----	----	----
383	----	383	----	----	----	----	----
389	389	389	----	----	389	389	----
408	408	408	----	----	----	----	----
422	----	422	422	----	----	----	----
467	468	468	468	468	----	----	----
548	548	----	548	548	----	----	----
616	616	616	616	----	----	----	----
697	697	697	697	----	----	----	----
743	743	743	----	743	----	----	----
----	----	----	761	----	----	----	----
----	----	----	----	806	----	----	----
----	----	----	826	826	----	----	----
----	----	874	----	874	874	----	----

Table A5. Resonant Frequencies for Single Shell, In-Air with Single Shaker Located on the Joint Band (Continued)

Accelerometers							
SY_1 (Hz)	A4 (Hz)	A5 (Hz)	A19 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
905	----	905	905	905	905	905	----
----	----	918	----	----	----	----	----
----	----	----	----	----	944	----	----
----	----	----	----	----	985	----	----
----	990	----	----	990	990	----	----

Table A6. Resonant Frequencies for Single Shell, In-Air with Single Shaker Located in the Middle of the End Shell

Accelerometers							
SZ_1 (Hz)	A10 (Hz)	A9 (Hz)	A23 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
----	----	----	41	----	----	----	----
263	----	263	263	----	----	----	----
272	272	272	272	272	272	----	272
334	----	----	334	----	----	----	----
352	352	----	352	352	352	----	----
428	----	----	----	----	----	----	----
467	----	----	----	467	----	----	----
575	575	575	575	575	575	----	575
635	635	635	635	635	635	----	----
639	----	639	----	639	639	639	----
----	646	----	----	----	----	----	----
985	985	985	----	985	985	----	----
----	----	----	990	----	----	----	----

Table A7. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, Out-of-Phase Located in the Middle of the Shell

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
245	----	245	245	245	----	----	----	----
----	----	----	----	----	----	----	252	----
----	----	----	----	----	----	262	----	----
272	272	272	272	272	272	272	----	----
352	352	352	352	----	352	352	----	----
467	467	467	467	----	467	467	----	467
575	----	575	575	----	575	575	----	----
616	616	616	616	----	----	----	----	----
----	----	----	----	----	635	635	----	----
646	646	646	646	646	646	646	646	----
----	743	----	----	----	----	----	----	----
----	----	761	761	----	----	----	----	----
----	827	----	----	----	827	----	----	----
----	----	----	874	----	----	----	----	----
905	----	----	----	----	905	905	----	----
----	928	----	----	----	928	928	----	----
----	----	----	----	----	----	987	----	----
----	----	----	990	----	----	990	----	----

Table A8. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, Out-of-Phase Located on the Joint Band

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
53	53	53	53	53	53	----	----	----
57	57	57	57	57	57	----	----	----
130	130	130	130	130	----	130	----	----
245	----	245	245	245	----	----	----	----
252	----	----	----	----	----	----	----	----
272	----	----	----	----	272	272	----	----
334	----	334	----	----	334	----	----	----
352	----	----	----	----	----	----	----	----
389	389	389	389	389	389	389	----	----
408	----	408	408	----	----	----	----	----
----	428	----	----	----	428	----	----	----
----	----	----	----	----	635	635	----	----
----	----	----	----	639	----	----	----	----
646	646	646	646	----	646	646	----	----
697	697	697	697	----	----	----	----	----
743	----	743	743	743	743	----	----	----
----	761	----	----	761	----	----	----	----
----	----	----	----	----	806	----	----	----
827	827	827	827	828	828	----	----	----
844	----	844	----	----	----	----	----	----
874	874	----	874	874	874	874	----	874

Table A8. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, Out-of-Phase Located on the Joint Band (Continued)

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
905	905	----	905	905	905	905	----	----
----	----	918	918	----	----	----	----	----
----	----	----	----	----	----	944	----	----
----	----	985	----	----	----	985	----	----
990	----	----	990	----	----	----	----	----

Table A9. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, Out-of-Phase Located in the Middle of the End Shell

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
41	41	41	41	41	----	41	----	----
----	----	----	----	----	53	53	----	----
----	----	----	----	----	245	245	----	----
----	252	----	----	----	252	252	----	252
263	263	263	263	----	----	----	----	----
334	334	----	334	----	----	----	----	----
352	352	352	352	----	352	352	----	----
389	389	----	----	389	389	389	----	----
----	----	----	----	----	408	----	----	----
422	----	----	----	----	----	----	----	----
467	467	----	----	----	467	----	----	----
----	----	----	----	----	548	548	----	----
575	575	575	575	575	----	575	----	575
635	635	635	635	635	635	635	----	635
----	----	----	----	----	646	646	----	----
----	----	----	----	----	743	----	----	----
806	806	806	----	806	806	----	----	----
----	844	----	----	----	844	----	----	----
----	----	----	----	----	905	----	----	----

Table A9. Resonant Frequencies for the Single Shell, In-Air with Both Shakers, Out-of-Phase Located in the Middle of the End Shell (Continued)

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
----	----	----	928	----	----	----	----	----
987	----	----	----	----	987	987	----	----
----	----	----	990	----	----	----	----	----

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Table A10. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located in the Middle of the Shell

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
54	54	54	54	54	54	----	----	----
58	58	58	58	58	58	----	----	----
----	236	236	236	----	----	----	236	----
249	249	249	249	249	249	249	----	----
----	----	----	----	263	----	----	----	----
----	----	----	268	268	268	----	----	----
538	538	538	538	----	538	538	----	----
----	----	----	----	----	----	----	627	----
----	----	----	----	----	----	----	638	----
----	----	647	----	----	----	----	----	----
666	666	666	666	666	----	----	666	----
----	----	----	----	----	673	673	----	----
----	----	----	----	----	689	----	----	----
----	----	----	----	----	----	695	----	695
711	711	711	711	711	----	----	711	----
721	----	724	724	----	724	----	----	----
729	729	729	729	----	----	----	----	----
753	753	753	753	753	----	----	753	----
771	771	771	771	----	----	----	----	----

Table A10. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located in the Middle of the Shell (Continued)

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
795	----	795	795	795	795	----	----	----
----	----	----	----	----	----	----	803	----
----	----	----	----	----	----	----	----	----
879	----	879	----	879	----	----	----	----
----	----	886	----	----	----	----	----	----

Table A11. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located on the Joint Band

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
----	133	----	----	----	----	----	----	----
236	----	236	236	236	----	----	----	----
249	----	----	----	249	249	249	249	249
254	----	254	----	----	----	----	----	----
----	----	----	----	----	268	----	----	----
313	313	313	313	----	313	313	----	----
----	----	----	----	----	322	----	----	----
351	351	351	351	----	351	351	----	----
360	----	360	360	360	360	360	360	----
378	378	378	379	----	----	379	----	----
482	482	----	----	----	----	----	----	----
----	----	----	----	----	538	----	----	----
548	----	----	----	----	----	----	----	----
602	602	602	602	----	602	----	----	----
614	----	----	----	----	----	----	----	----
----	----	627	----	----	----	----	----	----
----	----	----	----	638	----	----	----	----
647	----	----	----	----	----	----	----	----
660	----	660	660	----	660	660	----	----

Table A11. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located on the Joint Band (Continued)

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
673	673	673	673	----	----	----	673	----
----	----	----	----	772	----	----	772	----
----	----	----	753	----	----	----	----	----
----	----	----	772	----	----	----	----	----
785	----	----	----	----	----	----	785	----
----	----	----	----	803	----	----	----	----
----	879	----	----	879	----	----	----	----

Table A12. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located in the Middle of the End Shell

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
236	237	----	----	----	----	----	----	----
----	----	----	----	246	----	----	----	----
249	----	----	249	----	249	249	----	----
----	----	----	----	----	----	----	----	254
268	268	268	268	268	268	268	268	268
313	313	313	313	313	313	313	----	----
322	----	----	----	322	322	322	----	----
347	347	347	347	347	----	----	----	347
----	----	----	----	----	----	----	352	----
383	----	----	----	----	383	383	----	----
----	----	388	----	----	----	----	----	----
----	614	----	----	----	----	----	----	----
----	638	----	----	638	----	----	----	----
660	----	660	660	----	660	660	----	----
711	----	711	----	----	----	----	----	----
----	----	----	----	----	721	721	----	----
----	----	----	----	----	755	----	----	----
----	----	772	----	772	----	----	----	----
785	----	----	----	----	----	----	785	----

Table A12. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located in the Middle of the End Shell (Continued)

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
803	803	803	803	803	----	----	----	----
----	----	----	----	----	----	----	879	----
----	886	----	----	----	886	----	----	----
----	----	----	891	----	----	891	----	----
----	934	----	----	934	934	----	----	----

Table A13. Resonant Frequencies for Double Shell, In-Air with Single Shaker Located in the Middle of the End Shell

Accelerometers							
SX_1 (Hz)	A1 (Hz)	A2 (Hz)	A15 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
54	54	54	54	54	----	----	----
58	58	58	58	58	----	----	----
----	236	236	----	----	----	----	----
249	249	249	249	249	249	----	----
----	----	----	----	----	----	254	----
----	----	----	----	----	----	263	----
268	268	268	----	268	268	----	----
322	322	322	322	322	----	322	----
378	378	378	378	----	----	----	----
383	----	----	----	383	----	----	----
----	388	----	388	388	388	----	----
482	----	----	----	----	----	----	----
538	538	----	538	538	----	----	----
548	548	548	----	----	----	----	----
----	----	----	614	----	----	----	----
----	----	----	----	----	----	----	----
647	647	647	----	----	----	----	----
----	----	----	----	660	660	----	----
666	666	666	666	----	----	666	----
----	----	----	----	695	695	----	----

Table A13. Resonant Frequencies for Double Shell, In-Air with Single Shaker Located in the Middle of the End Shell (Continued)

Accelerometers							
SX_1 (Hz)	A1 (Hz)	A2 (Hz)	A15 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
711	711	711	711	----	----	----	----
729	729	729	----	----	----	----	----
753	753	753	753	----	----	----	----
772	772	772	772	----	----	----	----
795	795	----	795	795	----	----	----
----	----	----	----	----	----	----	----
879	----	----	----	----	----	----	----
----	----	----	886	----	----	----	----
891	----	----	891	----	----	----	----
934	----	----	----	----	----	----	----

Table A14. Resonant Frequencies for Double Shell, In-Air with Single Shaker Located on the Joint Band

Accelerometers							
SY_1 (Hz)	A4 (Hz)	A5 (Hz)	A19 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
54	54	54	54	54	----	----	----
58	58	58	58	58	----	----	----
133	133	133	133	----	----	----	----
236	236	236	236	----	----	----	----
----	----	----	----	249	249	249	249
254	254	254	----	----	----	----	----
----	----	----	----	268	----	----	----
313	313	313	313	313	313	313	----
350	350	350	350	350	----	----	----
361	361	361	361	361	361	361	----
377	377	377	379	----	----	----	----
----	----	----	----	482	----	----	----
----	----	----	538	----	----	----	----
549	549	----	----	----	----	----	----
602	602	602	----	602	----	----	----
----	----	----	----	614	614	614	----
628	628	628	----	----	----	----	----
647	----	----	----	----	----	----	----
----	660	660	----	660	660	660	----
673	673	673	----	----	----	----	----

Table A14. Resonant Frequencies for Double Shell, In-Air with Single Shaker Located on the Joint Band (Continued)

Accelerometers							
SY_1 (Hz)	A4 (Hz)	A5 (Hz)	A19 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
----	----	----	689	----	----	----	----
----	----	695	----	----	----	----	----
----	----	----	711	----	----	----	----
721	----	----	----	----	----	----	----
729	729	729	----	----	----	----	----
----	----	753	----	----	----	----	----
772	----	----	----	----	----	----	----
785	----	----	----	----	----	----	----
----	----	----	----	----	----	803	----
871	871	----	871	----	----	----	----
----	----	879	----	----	----	----	----
----	----	886	----	----	----	----	----

Table A15. Resonant Frequencies for Double Shell, In-Air with Single Shaker Located In the Middle of the End Shell

Accelerometers							
SZ_1 (Hz)	A10 (Hz)	A9 (Hz)	A23 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
54	----	----	----	54	54	----	----
58	----	----	----	----	----	----	----
----	----	----	246	----	----	----	----
249	249	249	----	249	249	----	----
----	----	----	----	----	----	----	254
268	268	268	268	268	268	----	----
313	313	313	313	----	----	----	----
----	322	----	322	----	----	----	----
347	347	347	347	----	----	----	----
----	----	----	----	----	360	----	----
----	----	383	----	----	383	----	----
388	388	----	----	388	388	----	----
538	538	----	----	538	538	----	----
----	----	548	----	548	548	----	----
602	602	602	----	----	602	----	----
----	----	----	614	----	----	----	----
----	----	----	----	638	----	----	----
660	660	660	----	660	660	----	----
----	----	----	----	673	673	----	----
689	689	689	689	----	----	----	----

Table A15. Resonant Frequencies for Double Shell, In-Air with Single Shaker Located In the Middle of the End Shell (Continued)

Accelerometers							
SZ_1 (Hz)	A10 (Hz)	A9 (Hz)	A23 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
----	----	----	----	695	----	----	----
----	----	----	----	721	----	----	----
----	----	----	----	729	729	----	----
785	785	785	785	----	----	----	----
----	----	----	----	795	----	----	----
803	803	803	803	----	----	----	----
891	----	891	----	----	----	----	----
934	934	934	----	----	----	----	934

Table A16. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located in the Middle of the Shell

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
54	54	----	----	----	----	----	----	----
58	58	----	----	----	----	----	----	----
249	249	249	249	----	249	249	----	----
----	----	----	----	263	----	----	263	----
268	----	268	268	268	268	268	----	----
322	322	322	322	----	----	----	322	----
----	378	----	378	----	----	----	----	----
383	----	----	----	----	----	----	383	----
388	388	388	----	388	388	388	----	----
482	----	482	482	----	----	----	----	----
602	----	602	----	----	602	602	----	----
----	----	627	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----
----	----	647	647	647	----	----	----	----
----	660	----	----	----	660	----	----	----
----	----	----	666	666	----	----	----	----
----	673	----	----	----	----	----	----	----
----	----	689	689	689	689	689	689	----
711	----	----	711	711	----	----	----	----

Table A16. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located in the Middle of the Shell (Continued)

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
729	----	729	729	----	----	----	----	----
753	----	753	753	----	----	----	----	----
785	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----
----	886	----	----	886	----	----	----	----
934	----	----	934	----	----	----	----	----

Table A17. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located on the Joint Band

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
54	54	54	54	54	54	----	----	----
58	58	58	58	58	58	----	----	----
133	133	133	133	133	----	----	----	----
236	----	----	236	----	----	----	----	----
----	246	----	----	246	----	----	----	----
----	----	----	----	----	249	----	----	----
254	----	----	254	----	----	----	----	----
268	----	----	----	----	268	----	----	----
313	----	----	313	----	313	----	----	----
351	----	----	351	----	351	----	----	----
360	----	360	360	360	360	----	----	----
378	----	378	378	----	----	----	378	----
383	383	----	----	----	----	----	----	----
----	----	----	388	388	388	----	----	----
627	----	627	627	----	627	----	----	----
647	----	647	----	----	----	----	----	----
----	----	----	----	660	----	----	----	----
----	689	689	689	689	----	----	----	----
----	----	----	----	----	----	----	711	----

Table A17. Resonant Frequencies for Double Shell, In-Air with Both Shakers, In-Phase Located on the Joint Band (Continued)

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
721	721	----	721	721	----	----	----	----
729	729	----	729	729	----	----	----	----
772	----	----	----	----	772	----	----	----
----	----	----	----	----	----	----	803	----
871	871	----	871	871	----	871	----	----
----	879	879	----	----	----	----	879	----
----	----	----	886	----	----	----	----	----
----	----	----	----	----	----	891	----	----

Table A18. Resonant Frequencies for Double Shell, In-Air with Both Shakers, Out-of-Phase Located in the Middle of the End Shell

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
54	54	54	----	----	54	54	----	----
58	58	58	----	----	58	58	----	----
----	236	236	----	----	236	236	----	----
246	----	----	----	246	----	----	----	----
----	----	----	----	----	254	254	----	254
----	----	263	----	----	----	----	----	----
----	----	----	----	268	----	----	----	----
313	313	313	----	----	----	----	----	----
322	----	----	----	----	----	322	----	----
347	347	347	347	347	----	----	----	----
----	----	----	----	----	378	378	----	----
----	----	----	----	----	383	383	----	----
----	----	----	----	388	----	----	----	----
538	----	538	----	----	538	538	----	----
----	----	----	548	----	548	548	----	----
602	----	602	----	----	----	----	----	----
614	614	614	614	614	614	----	----	----
638	638	638	638	638	638	638	638	----
660	----	660	660	660	660	----	----	----

Table A18. Resonant Frequencies for Double Shell, In-Air with Both Shakers, Out-of-Phase Located in the Middle of the End Shell (Continued)

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
673	673	----	----	----	673	673	----	----
688	688	688	688	688	----	----	688	----
----	----	----	----	----	695	695	----	----
----	----	----	----	----	753	----	----	----
----	----	----	----	----	----	----	772	772
785	----	785	----	----	----	----	785	----
803	803	803	803	803	----	----	----	----
----	----	----	----	----	----	----	879	----
----	886	----	----	----	----	----	----	----
----	891	----	----	----	----	----	----	----
934	934	----	934	----	----	----	----	----

Table A19. Resonant Frequencies for Single Shell, In-Water with Both Shakers, In-Phase Located in the Middle of the Shell

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
57	57	57	57	57	----	----	----	----
----	----	----	----	----	140	----	----	----
166	166	166	166	166	----	----	----	----
176	176	----	----	----	----	----	----	----
335	335	335	335	335	355	355	----	----
386	386	386	386	386	386	386	386	386
----	----	----	467	----	----	----	----	----
----	----	503	503	----	503	503	----	----
576	----	576	----	576	576	576	----	----
----	----	603	603	----	----	603	----	----
648	648	648	648	648	----	648	----	----
716	716	716	716	716	716	716	----	----
778	----	778	----	----	----	----	----	----
793	----	----	793	----	----	----	----	----
----	829	829	----	----	----	----	----	----
866	----	----	866	----	----	----	----	----
894	----	----	----	----	----	----	----	----
----	920	----	920	920	----	----	----	----
----	----	934	----	----	----	----	----	----
----	----	----	975	----	----	----	----	----

Table A20. Resonant Frequencies for Single Shell, In-Water with Both Shakers, In-Phase Located on the Joint Band

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
57	57	----	----	57	----	----	----	----
140	----	----	----	----	140	140	----	----
----	145	145	----	----	----	----	----	----
156	----	----	----	----	----	----	----	----
----	----	----	----	166	----	----	----	----
176	176	176	176	----	----	----	----	----
255	255	255	255	----	255	----	----	----
273	273	273	273	273	273	----	----	----
325	325	----	----	325	325	----	----	----
----	----	----	370	----	----	----	----	----
381	381	381	381	----	----	----	----	----
----	----	----	----	----	386	----	----	----
472	472	472	472	472	472	----	----	----
----	----	503	503	----	503	503	----	----
576	----	576	----	576	----	576	----	----
----	----	603	603	----	----	603	----	----
648	----	----	648	648	----	648	----	----
691	691	691	691	----	691	691	----	----
----	----	----	----	----	716	----	----	----
778	----	778	----	778	----	----	----	----

Table A20. Resonant Frequencies for Single Shell, In-Water with Both Shakers, In-Phase Located on the Joint Band (Continued)

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
----	782	----	782	----	782	----	----	----
789	----	----	----	----	----	----	----	----
----	----	----	----	----	----	793	----	----
829	829	----	----	----	829	829	----	----
832	832	----	----	----	----	----	----	----
866	----	----	----	----	----	----	----	----
----	911	----	911	----	----	911	----	----
934	----	----	----	----	934	----	----	----
975	975	975	975	975	975	----	----	----

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CBB:SIH:DAB:JEH:lhm

Table A21. Resonant Frequencies for Single Shell, In-Water with Both Shakers, In-Phase Located in the Middle of the End Shell

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
140	140	140	140	140	140	140	----	----
187	187	187	187	----	187	187	187	----
255	255	----	----	----	----	----	----	----
273	273	273	----	273	----	----	----	----
----	----	----	----	----	----	----	----	----
386	386	386	386	386	386	386	----	----
----	----	503	----	----	503	503	----	----
603	----	----	----	----	603	603	----	----
648	----	----	648	----	648	----	----	----
716	716	716	716	716	716	716	716	716
782	----	782	----	----	----	----	----	----
793	----	----	793	----	793	----	----	----
829	----	----	----	----	----	----	----	----
----	----	----	832	----	----	----	----	----
869	----	----	869	----	869	----	----	----
----	----	879	----	----	----	----	----	----
894	----	----	894	894	----	----	----	----
913	913	----	913	913	----	913	913	----

Table A22. Resonant Frequencies for Single Shell, In-Water with Single Shaker Located in the Middle of the Shell

Accelerometers							
SX_1 (Hz)	A1 (Hz)	A2 (Hz)	A15 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
57	----	----	57	----	----	----	----
166	166	166	----	----	----	----	----
----	----	----	----	----	176	----	----
187	187	187	187	187	187	----	----
----	----	----	273	273	----	----	----
335	335	335	335	335	----	----	----
----	----	----	----	----	340	----	----
386	386	386	386	386	386	----	----
----	467	467	----	----	467	----	----
----	----	----	----	472	----	----	----
----	503	503	----	503	----	----	----
576	576	----	576	----	576	----	----
----	----	603	----	----	603	----	----
648	648	648	648	648	648	----	----
716	716	716	716	716	716	----	----
778	778	----	----	----	----	----	----
793	793	793	793	----	793	----	----
866	----	----	----	----	866	866	866

Table A22. Resonant Frequencies for Single Shell, In-Water with Single Shaker Located in the Middle of the Shell (Continued)

Accelerometers							
SX_1 (Hz)	A1 (Hz)	A2 (Hz)	A15 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
----	869	869	869	869	----	----	----
894	----	----	----	----	----	----	----
920	----	920	920	----	920	----	----
975	975	975	----	975	----	----	----

Table A23. Resonant Frequencies for Single Shell, In-Water with Single Shell on the Joint Band

Accelerometers							
SY_1 (Hz)	SY_2 (Hz)	A5 (Hz)	A19 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
57	----	----	57	----	----	----	----
----	140	140	----	140	----	----	----
145	----	----	145	----	----	----	----
156	----	----	----	156	----	----	----
176	176	176	176	176	176	----	----
----	----	----	----	273	----	----	----
325	----	----	325	325	----	----	----
----	370	370	----	370	----	----	----
381	381	381	381	----	----	----	----
----	----	----	----	386	----	----	----
----	444	----	444	----	----	----	----
472	472	472	472	472	----	----	----
576	576	576	576	576	576	576	----
603	603	603	----	603	603	----	----
----	----	648	648	648	648	----	----
----	----	691	691	----	----	----	----
----	----	----	----	716	716	----	----
778	778	----	778	----	----	----	----

Table A23. Resonant Frequencies for Single Shell, In-Water with Single Shell on the Joint Band (Continued)

Accelerometers							
SY_1 (Hz)	SY_2 (Hz)	A5 (Hz)	A19 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
----	----	782	----	----	----	----	----
793	----	----	----	793	----	----	----
829	----	829	----	829	829	----	----
----	----	----	----	832	----	----	----
869	----	----	----	----	869	----	----
934	----	934	----	934	----	----	----
975	975	975	975	975	975	----	----

Table A24. Resonant Frequencies for Single Shell, In-Water with Single Shell Located in the Middle of the End Shell

Accelerometers							
SZ_1 (Hz)	A10 (Hz)	A9 (Hz)	A23 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
140	140	140	140	----	----	----	----
156	156	----	156	----	156	----	----
----	----	----	----	166	----	----	----
176	176	----	176	----	176	----	----
187	187	187	187	187	187	187	----
----	273	----	----	----	----	----	----
340	340	340	340	340	340	----	----
386	386	386	386	386	386	386	386
444	----	----	----	----	----	----	----
----	----	----	----	467	467	----	----
----	472	----	----	----	----	----	----
----	----	----	----	503	503	----	----
----	----	576	576	576	----	----	----
603	603	603	----	603	603	----	----
648	----	648	----	648	648	----	648
----	----	----	----	691	691	----	----
716	716	716	716	716	716	716	716
782	782	----	----	----	----	----	----

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Table A24. Resonant Frequencies for Single Shell, In-Water with Single Shell Located in the Middle of the End Shell

Accelerometers							
SZ_1 (Hz)	A10 (Hz)	A9 (Hz)	A23 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
789	----	----	----	789	----	789	789
----	----	793	793	----	----	----	----
829	----	----	829	----	829	829	----
----	832	832	----	----	----	----	----
----	----	----	----	866	----	----	----
869	----	869	869	----	869	----	----
894	----	----	894	----	----	----	----
913	----	913	913	----	----	----	----
975	----	----	----	----	----	----	----

Table A25. Resonant Frequencies for Single Shell, In-Water with Both Shakers, Out-of-Phase Located in the Middle of the Shell

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
----	57	----	----	----	----	----	----	----
----	----	----	----	----	140	----	----	----
145	145	145	145	145	----	----	----	----
166	166	166	166	166	----	----	166	----
----	----	176	176	176	176	176	----	----
187	187	187	187	187	187	187	----	----
----	273	----	----	----	273	----	273	----
340	----	----	----	----	340	----	----	----
386	386	386	386	386	386	386	386	----
----	----	467	467	467	----	----	----	----
472	472	----	----	----	----	----	----	----
----	----	----	----	----	503	----	----	----
576	576	576	----	----	576	576	----	----
----	----	603	603	603	----	603	----	----
648	----	648	648	648	648	648	----	----
716	716	716	716	716	716	716	716	716
789	789	----	----	----	789	789	----	----
----	----	793	793	793	----	----	----	----
866	----	----	----	----	----	----	----	866
----	869	869	869	869	869	869	----	----
894	----	----	----	----	----	----	----	----

Table A25. Resonant Frequencies for Single Shell, In-Water with Both Shakers, Out-of-Phase Located in the Middle of the Shell (Continued)

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
----	----	----	----	----	----	----	----	913
920	920	----	920	920	----	----	----	----
975	----	----	975	975	975	----	----	----

Table A26. Resonant Frequencies for Single Shell, In-Water with Both Shakers, Out-of-Phase Located on the Joint Band

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
57	57	----	----	57	----	----	----	----
----	----	----	----	----	140	----	----	----
----	145	----	----	----	----	----	----	----
325	325	----	----	----	325	----	----	----
----	370	370	370	370	370	----	----	----
----	386	----	----	----	386	386	386	----
444	444	444	444	----	444	444	444	----
----	467	----	----	467	----	----	----	----
472	----	472	472	----	----	----	----	----
----	503	503	503	503	503	503	----	----
576	576	576	----	576	576	576	576	----
603	----	603	603	603	603	603	----	----
648	648	----	648	648	648	648	----	----
----	----	----	----	----	716	716	----	----
778	778	778	----	----	----	----	----	----
----	----	----	----	----	782	----	----	----
869	----	----	----	----	----	----	----	----
934	----	----	----	----	934	----	----	----
975	----	----	----	----	975	----	----	----

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Table A27. Resonant Frequencies for Single Shell, In-Water with Both Shakers, Out-of-Phase Located in the Middle of the End Shell

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
140	140	140	----	----	----	----	----	----
----	----	----	----	----	165	165	----	----
176	----	176	----	----	176	176	----	----
187	187	187	187	----	187	187	----	----
----	273	----	----	----	----	----	----	----
340	340	340	340	----	340	340	----	340
386	386	386	386	386	386	386	386	386
----	----	----	----	----	467	467	----	----
----	----	503	503	----	503	503	----	----
576	576	----	576	576	576	----	----	----
603	----	----	603	603	603	603	----	----
648	----	----	648	648	648	648	----	648
716	716	716	716	716	716	716	716	716
782	----	782	----	----	----	----	----	----
----	----	----	----	----	789	----	----	----
793	----	----	----	----	----	793	----	----
829	----	----	----	----	----	----	----	----
832	----	----	----	----	----	----	----	----

Table A27. Resonant Frequencies for Single Shell, In-Water with Both Shakers, Out-of-Phase Located in the Middle of the End Shell (Continued)

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
895	----	----	----	----	----	----	----	----
913	----	----	913	913	----	----	----	----
975	----	----	----	----	----	----	----	----

Table A28. Resonant Frequencies for Double Shell, In-Water with Both Shakers, In-Phase Located in the Middle of the Shell

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
47	----	47	47	47	----	----	----	----
195	----	195	195	----	----	----	----	----
----	----	217	----	----	----	----	----	----
----	----	----	----	----	423	----	----	----
597	----	----	----	----	597	----	----	----
----	767	----	----	767	767	----	----	----

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Table A29. Resonant Frequencies for Double Shell, In-Water with Both Shakers, In-Phase Located on the Joint Band

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
140	----	140	140	----	----	----	----	----
195	195	195	195	----	195	----	----	----
282	282	282	282	----	282	----	----	----
301	301	301	301	----	301	----	----	----
----	----	----	----	----	423	----	----	----
----	----	438	----	----	----	----	----	----
----	----	519	519	----	519	----	----	----

Table A30. Resonant Frequencies for Double Shell, In-Water with Both Shakers, In-Phase Located in the Middle of the End Shell

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
----	----	164	----	----	----	----	----	----
----	----	----	----	----	195	195	----	----
217	217	217	217	----	217	----	----	----
282	----	282	----	----	----	----	----	----
301	301	301	----	----	301	----	----	----
----	423	423	423	423	----	----	----	----
----	754	754	----	----	----	----	754	----

Table A31. Resonant Frequencies for Double Shell, In-Water with Single Shell Located in the Middle of the Shell

Accelerometers							
SX_1 (Hz)	A1 (Hz)	A2 (Hz)	A15 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
----	----	47	47	----	----	----	----
----	140	----	----	----	----	----	----
185	185	185	185	----	----	----	----
----	195	195	----	----	----	----	----
----	217	217	217	217	----	----	----
----	----	301	301	301	----	----	----
438	438	438	438	----	----	----	----
----	519	----	----	----	----	----	----
597	----	597	----	----	----	----	----
669	669	669	----	----	669	----	----
767	767	767	767	767	----	----	----

Table A32. Resonant Frequencies for Double Shell, In-Water with Single Shell Located on the Joint Band

Accelerometers							
SY_1 (Hz)	A4 (Hz)	A5 (Hz)	A19 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
142	142	142	----	----	----	----	----
195	195	195	195	195	----	----	----
----	----	----	282	282	----	----	----
----	301	301	301	301	----	----	----
----	423	423	----	----	----	----	----
438	----	----	----	----	----	----	----
519	519	519	519	519	----	----	----
----	669	669	----	----	669	----	----
----	----	----	----	754	----	----	----

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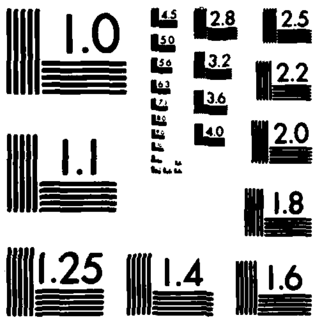

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Table A33. Resonant Frequencies for Double Shell, In-Water with Single Shaker Located in the Middle of the End Shell

Accelerometers							
SZ_1 (Hz)	A10 (Hz)	A9 (Hz)	A23 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
164	164	----	164	----	----	----	----
217	217	----	217	----	217	----	----
282	----	----	----	----	----	----	----
301	301	----	301	----	----	----	----
423	423	423	423	423	----	----	----
----	----	----	----	669	----	----	----
----	754	754	754	----	----	754-	----

Table A34. Resonant Frequencies for Double Shell, In-Water with Both Shakers, Out-of-Phase Located in the Middle of the Shell

Accelerometers								
SX_1 (Hz)	SX_2 (Hz)	A1 (Hz)	A2 (Hz)	A14 (Hz)	A10 (Hz)	A9 (Hz)	TAX(1Y) (Hz)	TAX(1Z) (Hz)
142	142	142	142	----	----	----	----	----
185	185	185	----	185	185	----	----	----
217	217	217	217	217	217	----	----	----
301	301	301	301	----	----	----	----	----
438	438	438	438	438	438	----	----	----
----	----	----	519	----	----	----	----	----
669	----	----	----	----	----	----	----	----
767	767	767	767	767	767	767	----	----

Table A35. Resonant Frequencies for Double Shell, In-Water with Both Shakers, Out-of-Phase Located on the Joint Band

Accelerometers								
SY_1 (Hz)	SY_2 (Hz)	A4 (Hz)	A5 (Hz)	A18 (Hz)	A10 (Hz)	A9 (Hz)	TAY(1Y) (Hz)	TAY(1Z) (Hz)
47	----	----	----	----	----	----	----	----
142	----	----	----	----	----	----	----	----
185	----	----	----	----	----	----	----	----
----	----	----	423	----	423	----	----	----
----	----	438	----	----	----	----	----	----
519	----	----	----	----	----	----	----	----
597	597	597	----	597	----	----	----	----
669	----	669	----	----	----	669	----	----
767	767	767	----	----	----	----	----	----

Table A36. Resonant Frequencies for Double Shell, In-Water with Both Shakers, Out-of-Phase Located in the Middle of the End Shell

Accelerometers								
SZ_1 (Hz)	SZ_2 (Hz)	A10 (Hz)	A9 (Hz)	A22 (Hz)	A1 (Hz)	A2 (Hz)	TAZ(1Y) (Hz)	TAZ(1Z) (Hz)
----	217	217	----	----	217	----	----	----
423	423	423	423	423	423	423	423	423
----	----	----	----	----	669	----	----	----
754	754	754	----	754	----	----	754	----
----	----	----	----	----	767	767	----	----

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